Growth Curve of Dairy Artificial Insemination Bulls Raised under Thai Tropical Conditions

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Abstract

The objective of this research was to evaluate the growth curve of dairy artificial insemination bulls under Thai tropical conditions. Data consisted of 4,963 monthly body weights from 140 bulls from the Semen Production and Dairy Genetic Evaluation Center of the Dairy Promotion Organization of Thailand collected from 1996 to 2015. Four breed groups were defined based on Holstein (H) fraction: BG1 ($0.96 \leq H \leq 1.00$), BG2 ($0.91 \leq H < 0.96$), BG3 ($0.86 \leq H < 0.91$), and BG4 ($0.44 \leq H < 0.86$). Linear (Quadratic) and nonlinear (Gompertz, Logistic, Von Bertalanffy and Brody) models were compared for goodness of fit using -2logL, Akaike Information Criterion (AIC), Corrected AIC (AICC) and Bayesian Information Criterion (BIC). The model with the lowest values for these four criteria was Quadratic. Predicted weights at 30 mo and 60 mo of age were higher for bulls in BG2 than bulls in BG1, BG3, and BG4. Growth curves from these bulls would be useful to identify sires expected to produce steers with faster growth rates and heifers with younger ages at first calving. Unfortunately, weights from steer and heifer progeny from these bulls were unavailable. Consequently, progeny weights would need to be collected if genomic selection for growth traits were to be implemented in the Thai multibreed population.

Keywords: Artificial insemination; Dairy bull; Growth curves; Tropical

Introduction

Knowledge of growth patterns in cattle is important for making appropriate herd management, nutrition and selection decisions aimed at improving beef production efficiency. Although beef steers supply the majority of beef in Thailand, dairy steers are also fattened to cover beef shortages, to stabilize prices of beef products, and to provide a choice to consumers demanding high quality beef. Unfortunately, there is currently no information available on growth patterns and slaughter ages of dairy steers in either farms or feedlots in Thailand. However, weight data exists on Holstein (H) and Holstein crossbred bulls belonging to the Semen Production and Dairy Genetic Evaluation Center of the Dairy Farming Promotion Organization of Thailand (DPO) from near birth to eight years of age. These data could be used to gain knowledge on expected growth curves of their progeny fed in their own farms of origin or in feedlots as well as insights on expected mature weight of their daughters in dairy farms.

Most cattle in the Thai dairy multibreed population have a high H percentage with various fractions of other *Bos taurus* (Brown Swiss, Jersey, Red Dane) and (or) *Bos indicus* (Brahman, Red Sindhi, Sahiwal and Thai Native) breeds (Koonawootrittriron *et al.*, 2009). Knowledge of growth curves of artificial insemination sires of various H fractions at the DPO would help identify sires whose steer progeny would be expected to have faster growth rates and shorter fattening times and whose daughters would be of moderate mature size. This would help improve genetic selection for growth and dairy production efficiency, which in turn would be expected to increase farm profitability. A variety of mathematical models can be used to analyze growth curves as well as to predict body weight from partial records including Brody (Brody, 1945), Von Bertalanffy (Von Bertalanffy, 1957), Logistic (Nelder, 1961), Gompertz (Gompertz, 1825), and polynomial regression model. Thus, the objective of this research was to evaluate the growth curve of bulls from the Dairy Farming Promotion Organization of Thailand to obtain insights on expected slaughter age of steer progeny of various H percentages and on expected mature weights of their daughters using five mathematical models (Quadratic, Logistic, Gompertz, Von Bertalanffy, and Brody).

Materials and Methods

Animals and data

A total of 140 bulls from the Semen Production and Dairy Genetic Evaluation Center of the DPO were used in this research. These bulls were the progeny of 55 sires and 136 dams. DPO personnel chose potential sires and dams of bulls based on EPD for milk production. Sires of bulls belonged to the Semen Production and Dairy Genetic Evaluation Center of the DPO and dams of bulls were from 59 dairy farms in Central, Northern, Northeastern, and Southern Thailand. Bulls were raised under the same nutritional regimen, management and health care at the Semen Production and Dairy Genetic Evaluation Center of the DPO located in Muaklek, Saraburi province, Thailand, [14º38´24.7″ latitude North, 101º11´57.2″ longitude East].

The Thai multibreed population is the product of an upgrading process from various *Bos indicus* and *Bos taurus* breeds to Holstein. Breeds represented in the multibreed dairy population were Holstein, Brahman, Jersey, Red Dane, Red Sindhi, Sahiwal and Thai Native. Ninety four percent of the bulls in this population were H crossbreds, and the remaining 6% were purebred H. The average H fraction of bulls was 92.5% (minimum = 44%; maximum = 100%). Considering the H percentage of the bulls in the population, four breed groups were constructed: BG1 ($0.96 \leq H \leq 1.00$); BG2 ($0.91 \leq H < 0.96$); BG3 ($0.86 \leq H < 0.91$) and BG4 ($0.44 \leq H < 0.86$). Numbers of animals per breed group and total, numbers of records per breed group and total, and number of records per animal per breed group and total are shown in Table 1.

The dataset consisted of monthly body weights (n = 4,963) from 140 dairy bulls born from 1996 to 2015. Bulls were weighed monthly starting from birth until a bull completed 25,000 doses of frozen semen or when a bull reached approximately 96 mo of age. Monthly body weights of bulls younger than 5.5 mo of age and older than 96 mo of age were excluded from the analysis because of missing and (or) erroneous information.

Climate, housing and management

The weather characteristics in Central of Thailand are influenced by tropical monsoons, the Southwest monsoon from May to October and the Northeast monsoon from October to February. Temperatures in this region during the years of the study (1996 to 2015) ranged from 15 ^{o}C to 34 ^{o}C, relative humidity (RH) fluctuated between 33% and 97%, and average rainfall averaged 1,113 mm/yr. Seasons were classified as winter (November to February; 14.5 ^{o}C to 31.6 ^{o}C, 65% RH, 50 mm rain/season), summer (March to June; 20.8 ^{o}C to 34.2 ^{o}C, 72% RH, 339 mm rain/season), and rainy (July to October; 23.2 ^{o}C to 31.8 ^{o}C, 77% RH, 724 mm rain/season; Thai Meteorological Department, 2015).

Bulls were raised in open barns. Each bull was kept in a 4×22 m^2 stall with a raised area and an exercise area. The raised area was 4×6 m^2, with a concrete floor and a tile roof (2.5 to 3 m high). The exercise area was 4×16 m^2, with dirt floor and no roof. Feed and water bunks were located in the front of the stall. Bulls were kept in their stalls at all times, except when semen was collected.

Bulls were fed 4 to 6 kg/d of concentrate (14 to 16% of CP) and had free access to fresh roughage, water, and a mineral supplement throughout the year. The concentrate was purchased from a local company (Charoen Pokphand Foods, Bangkok, Thailand). Its ingredients included protein sources (palm meal, soybean meal, cotton seed meal, leucaena), energy sources (cassava, rice bran, broken rice, fat from animals and plant, molasses), and mineral and vitamin sources (di-calcium and premixes). Fresh roughage consisted of Guinea (*Panicum maximum*), Ruzi (*Brachiaria ruziziensis),* Napier (*Pennisetum purpureum*), and

Para (*Brachiaria mutica*) grasses cut and carried to bull stalls. Bulls were also given Guinea and Ruzi grass hay and silage during the dry season (November to March) when fresh grass was scarce. Lastly, bulls were vaccinated against Foot and Mouth Disease (FMD), Tuberculosis (TB), and were dewormed every six months.

Statistical analysis

Bull growth data were analyzed using the following five models:

Model 1: Quadratic

$$y_t=b_0+b_1t+b_2t^2+e_t \quad (1)$$

Model 2: Gompertz (Gompertz, 1825)

$$y_t= A\exp\left(-B\exp(-kt)\right)+e_t \quad (2)$$

Model 3: Logistic (Nelder, 1961)

$$y_t= A\ (1+B\exp(-kt))^{-1}+e_t \quad (3)$$

Model 4: Von Bertalanffy (Von Bertalanffy, 1957)

$$y_t= A\ (1-B\exp(-kt))^3+e_t \quad (4)$$

Model 5: Brody (Brody, 1945)

$$y_t= A\ (1-B\exp(-kt))+e_t \quad (5)$$

Where y_t is the body weight (kg) at age t (mo) corrected by contemporary group (year-month of birth) and heterosis fixed effects, b_0 is the initial body weight, b_1 is the linear regression coefficient, b_2 is the quadratic regression coefficient, A is the asymptotic mature weight, B is the degree of maturity at birth, k is the maturing rate, and e_t is the residual. Model 1 was analyzed using the mixed procedure of SAS (SAS, 2011), whereas models two to five were analyzed with the NLMIXED procedure of SAS.

Goodness of fit for the five models was assessed using four fit statistics: 1) -2logL, where logL is the natural logarithm of the likelihood function; 2) Akaike Information Criterion (AIC) = -2logL + 2k, where k is the number of parameters (Akaike, 1974); 3) Corrected Akaike Information Criterion (AICC; Burnham and Anderson, 1998) = -2logL + 2kn / (n - k - 1), where, n is the number of observations, and k is the number of parameters; and 4) Schwarz Bayesian information criterion (BIC; Schwarz, 1978) = -2logL + klog(n). The model with the smallest -2logL, AIC, AICC and BIC values was chosen to be the best for fitting bull growth curves in this population. The chosen model was used to compute parameters for each of the four breed groups of bulls. Parameters for each breed group were used to compute weights at various ages to plot growth curves for the four breed groups.

Results and Discussion

Growth data

Fig.1 show a scatter plot of bull weights from 5.5 mo to 96 mo of age. This plot contains bull weights from all bulls collected at ages ranging from 5.5 mo to 96 mo of age. The average number of weights per bull was 35.6 (SD = 20.2). The scatter plot shows that bull growth followed relative straight path until approximately 60 mo of age, then it plateaued. These bull weight data can be utilized to obtain some information on the growth patterns of their steer progeny fed for beef (first 30 mo of age) and of their daughters reared as replacement dairy cows (all mo). Weights in Fig.1 could be divided into 3 phases: 1) Early growth: from 5.5 mo to 30 mo of age; 2) Late growth: from 30 mo to 60 mo of age; and 3) Maturity: after 60 mo of age, where body weight will fluctuate depending on environmental factors (climate, nutrition, health). These phases will be considered in the discussion of prediction models for bull growth and predicted growth curves for animals of four breed groups in the Thai multibreed population.

Overall goodness of fit of growth models

Table 2 contains the values of the four goodness of fit statistics used to compare the five models used in this study. The Quadratic model had the smallest -2LogL, AIC, AICC, and BIC values, thus it was the model that best fitted the growth data from 5.5 mo to 96 mo of age. Model rankings were identical for -2LogL, AIC, and AICC (Quadratic, Logistic, Gompertz, Von Bertalanffy, and Brody), and these rankings were similarly identical to that of BIC where the Quadratic model was first, and Brody was fifth. Values of AIC, AICC and BIC differed because of the values of the adjustment factors applied to -2LogL. The AIC adjusts -2LogL by adding a penalty twice the number of parameters involved in each model (2k), and AICC adjusts -2LogL for number of parameters k and sample size n (2kn/(n - k - 1). For large samples (n large), the AICC correction approaches 2k, thus AICC approached AIC and both of them will tend to select the same model (Lee and Ghosh, 2009). Conversely, BIC includes a value of total model parameters multiplied by the natural logarithm of total records (klog(n)), which will increase as n increases, hence it is more a more stringent statistic than AIC and AICC (Cobuci et al., 2011; Dziak et al., 2012).

No previous growth curve studies including Quadratic, and the four nonlinear models considered here (Gompertz, Brody, Von Bertalanffy, and Logistic) were found in the literature. Among nonlinear models, the Von Bertalanffy model was found to provide a better fit for growth curves than Gompertz, Logistic, Brody, and Richards in Holstein females (Berry et al., 2005). The Von Bertalanffy model also fitted growth better in a group of Holstein, Ayrshire and Holstein-Ayrshire crossbred females than Gompertz and Logistic models, which tended to overestimate early weights and to underestimate mature weights (Perotto et al., 1992; García-Muñiz et al., 1998). However, the Brody model fitted the growth curve of Jersey cows better than the Logistic, Von Bertalanffy, and Gompertz (Brown et al., 1976), although the best model occurred with the Richards function (Richards, 1959). In beef cattle, the Von Bertalanffy model fitted the growth curve of Spanish Retinta beef cows than Brody (López de Torre et al., 1992). Conversely, the Brody model provided a better fit to the growth curve of Nellore cattle than Gompertz and Von Bertalanffy (Forni et al., 2009), Hereford and Charolais-Angus-Galloway crossbred cattle than the Logistic and Von Bertalanffy models (Goonewardene et al., 1981), and Hereford and Brahman-Hereford crossbreds than the Logistic, Von Bertalanffy, and Gompertz (Brown et al.,1976). However, the Richards model (Richards, 1959) yielded the best growth curve fit in the last two studies (Brown et al.,1976; Goonewardene et al., 1981). Clearly, no single growth function provided a uniformly better fit across studies involving a variety of dairy and beef cattle breeds. In addition to the genetic composition of cattle and environmental conditions (management, nutrition, climate, health conditions), sample size may also have contributed to differences among models. Thus, although the Quadratic model was found to fit the growth of dairy bulls between 5.5 and 96 mo of age better than the other four models with the currently available data, this outcome may change in the future as additional data are collected.

Predicted growth curves by growth phase

Table 3 presents estimates of parameters and their standard errors for the five models in this study, and Fig. 2 shows the corresponding bull growth curves predicted using these parameters. The plot of actual weights over age (Fig. 1) showed that the body weight of bulls in this study increased until they reached maturity at approximately 60 mo of age, then bull weights fluctuated and appeared to slightly decrease until 96 mo of age. The shape of the growth curves for the five models was similar during early and late growth, but differed at maturity. All models tended to fit growth in the early and late growth periods well. However, mature weights tended to be underestimated by the Quadratic model and overestimated by the four nonlinear models.

A description of the predictive ability of the five models during the three growth stages is shown in Table 4 in terms of means and SD of differences between predicted and actual body weights during early growth, late growth, and maturity. The Logistic model generated the largest differences between predicted and actual weights of all models for early growth, whereas the Brody model generated the largest differences between predicted and actual weights for late growth and maturity. The Quadratic and Von Bertalanffy models tended to slightly overestimate bull weights during early growth (Quadratic: 2.67; Von Bertalanffy: 0.45), underestimate weights during late growth (Quadratic: -1.64; Von Bertalanffy: -4.94), and overestimate wights at maturity (Quadratic: 7.53; Von Bertalanffy: 10.63). The Logistic model overestimated weights during early growth (13.31), slightly underestimated weights during late growth (-0.51), and overestimated weights at maturity (11.84) more than the other models, except Brody. The Gompertz model tended to underestimate weights during early growth (-1.50) and late growth (-3.59), and to overestimate weights at maturity (7.09). The Brody model overestimated weights during early growth (4.66), underestimated weights during late growth (-11.39), and grossly overestimated weights at maturity (18.06), producing the worst fit of all models in late growth and maturity. Considering the simplicity of the Quadratic model and the reasonably small differences in all growth phases, this model should be preferred to nonlinear models if genetic or genomic evaluation for growth traits were to be conducted in the Thai dairy multibreed population, particularly if applied using Legendre polynomials or Splines.

To analyze the mean growth performance of the set of bulls here, weights at 5.5 mo, 30 mo, and 60 mo of age were predicted using the best model (Quadratic). Predicted weights with the Quadratic model indicated that mean bull weight increased by an average of 445 kg during the early growth period (168 kg at 5.5 mo to 613 kg at 30 mo of age), and by 274 kg during the late growth period (613 kg 30 mo to 887 kg at 60 mo of age). This indicated a decrease in growth rate of 62% between early and late growth. A similar pattern of growth was found in US Holstein (Calo et al., 1973), where bull weight increased by 599 kg during early growth (218 kg at 6 mo to 817 kg at 30 mo of age) and by 197 kg (817 kg at 30 mo to 1014 kg at 60 mo of age) during late growth, a decrease of 33% in their growth rate. Bull weights after 60 mo of age fluctuated around their mature weight because the feeding objective was to provide them with enough food to be an appropriate condition for artificial insemination. The pattern of growth observed in bulls from the Thai multibreed population reflected the typical cattle growth curve where there is an acceleration phase, then a point of inflection between early and late growth where the rate of growth decreases steadily until reaching maturity where bull weight remains relatively constant over time.

Predicted growth curves by breed group

Quadratic regression coefficients were estimated for animals in each of the four breed groups specified according to their breed composition (Table 5). These within-breed group quadratic regression coefficients were used to compute predicted values for each animal at every age in all four breed groups. A description of the predicted ability of the Quadratic model in terms of means and SD of differences between predicted and actual weights in each growth period for each breed group and the complete dataset is presented in Table 6. The Quadratic model underestimated BG2 weights in all growth phases, tended to overestimate BG3 and BG4 weights, and yielded the closest predictions during early and late growth for BG1 than for any other breed group. Bull predicted weights were subsequently plotted against age to construct growth curves for the four breed groups (Fig. 3). Predicted weights of bulls in BG2 were higher than those from BG1, BG3, and BG4 during the early growth period (5.5 to 30 mo of age) and the late growth period (30 to 60 mo of age). The rate of growth of BG3 and BG4 bulls until 60 mo of age was lower than that of BG1 and BG2 resulting in weights at 60 mo of age that were approximately 25 kg lower than those of BG1 and BG2. Predicted weights of bulls at maturity tended to be higher for BG2 and BG3 than BG1 and BG4.

The Quadratic model predicted weights indicated that bulls with an H fraction equal or greater than 96% (BG1) had the fastest rate of early growth and that bulls with an H fraction between 44% and 86% (BG4) had the lowest rate of late growth (Fig. 3). The predicted growth rate of bulls in BG1, BG2, and BG4 followed similar patterns throughout early growth, late growth and maturity. However, although the predicted growth rate of bulls in BG3 was lower than BG1, BG2, and BG4 during the early and late growth periods, it became higher than these breed groups at maturity. Caution should be exercised when interpreting the predicted weights from the Quadratic model in this population because of the large SD of the differences between predicted and actual weights for all breed groups in all growth phases, particularly for BG3 in the early growth phase.

Meat demand in Thailand per year (181,000 tons, equivalent to 1.26 million animals) exceeds the amount of available meat from beef cow-calf operations (0.97 million animals; Osothongs et al., 2016). This unmet demand could be largerly covered by feeding excess males from dairy cattle operations (509,524 animals). In a recent meat production study, crossbred steers of unknown H percentage had an average slaughter weight of 576.7 kg (SD =76.0 kg), carcass weight of 312.4 kg (SD = 42.8 kg), dressing percentage of 54.2 % (SD = 2.3 %), and a marbling score of 1.8 (SD = 0.8; Pluemjai et al., 2016). The slaughter weight in this study (576.7 kg) was achieved at approximately 27 mo for BG1 and BG2, 28 mo for BG4, and 29 mo for BG3, suggesting that the higher the H percentage the shorter the time to slaughter (assuming a similar feeding regime in a feedlot). More intensive fattening regimens could be used to speed up growth and reduce age at slaughter. Growth curves of sires of feedlot steers could be used to help identify bulls whose steer progeny would be expected to have faster growth rates and shorter fattening times. Another use of bull growth information concerns replacement females that have enough growth capability to produce milk under the open-housing, feeding, and climate conditions in Thailand. Predicted bull mature weights for the four bull breed groups (Fig. 3) suggest that daughters of bulls in breed groups 2 and 3 would tend to be larger than those from breed groups 1 and 4. However, these are phenotypic rather than genetic predictions. A selection program to select mature weight of replacement females would require genetic or genomic predictions of all animals in the breeding population (males and females) based on pedigree and weights collected at various ages, as well as genotypes for genomic predictions. Although genotypes are currently collected in the Thai multibreed dairy population, weights are not collected on either males or females. Perhaps a study addressing the economic advantages of genomic selection for meat production with dairy animals may encourage Thai dairy producers to collect weight information.

The Quadratic model provided the best fit to the growth of dairy bulls in the Thai population between 5.5 and 96 mo of age. Bull predicted weights increased faster during the early growth phase (6 to 30 mo of age), slowed down during the late growth phase (30 to 60 mo of age), and tended to decrease during the maturity phase (60 to 96 mo of age). Bulls in BG2 ($0.91 \leq H < 0.96$) had the fastest rate of early growth, late growth, and maturity until approximately 76 mo of age, when it was overtaken by bulls in BG3 ($0.86 \leq H < 0.91$). Bulls in BG3 had the slowest rates during the early and late growth periods and ended up with the fastest rate during the maturity period. Bulls in BG1 and BG4 had intermediate growth rated between BG2 and BG4 during the early and late growth periods and were the slowest in the maturity period. Growth curves of bulls from Thai artificial insemination centers like the DPO would be useful to identify sires expected to produce steers with fast growth rates in the feedlot as well as heifers with younger ages at first calving. Unfortunately, weights from steer and heifer progeny from these bulls were unavailable. Consequently, weights from male and female progeny would need to be collected if genomic selection for growth traits were to be implemented in the Thai dairy multibreed population.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Table 1 Number of animals, number of records and number of records per animal per breed group and total

Breed group[a]	Number of animals	Number of records	Number of records per animal
BG1	63	2276	36
BG2	34	1300	38
BG3	24	767	32
BG4	19	620	33
Total	140	4963	36

[a] BG1 = 0.96 ≤ H ≤ 1.00, BG2 = 0.91 ≤ H < 0.96, BG3 = 0.86 ≤ H < 0.91, and BG4 = 0.44 ≤ H < 0.86

Table 2 Comparison of growth models using -2log Likelihood (-2logL), Akaike Information Criterion (AIC), Corrected Akaike Information Criterion (AICC), and Schwarz Bayesian Information Criterion (BIC)

Model	-2logL	AIC	AICC	BIC
Quadratic	54068	54070	54070	54076
Logistic	54097	54105	54105	54131
Gompertz	54101	54109	54109	54135
Von Bertalanffy	54131	54139	54139	54165
Brody	54306	54314	54314	54340

Table 3 Parameter values and standard errors by growth model

Model	Parameter[a]					
	b_0	P-value	b_1	P-value	b_2	P-value
Quadratic	37.77 ± 3.46	0.0001	24.25 ± 0.18	0.0001	-0.1681 ± 0.0021	0.0001
	A		B		K	
Logistic	912.92 ± 3.36	0.0001	0.0671 ± 0.0007	0.0001	3.0427 ± 0.0302	0.0001
Gompertz	923.31 ± 3.63	0.0001	2.3134 ± 0.0251	0.0001	0.0592 ± 0.0007	0.0001
Von Bertalanffy	937.04 ± 3.98	0.0001	0.5887 ± 0.0053	0.0001	0.0513 ± 0.0006	0.0001
Brody	982.73 ± 5.34	0.0001	1.0556 ± 0.0063	0.0001	0.0354 ± 0.0005	0.0001

[a] b_0 = initial body weight, b_1 = linear regression coefficient, and b_2 = quadratic regression coefficient, A = asymptotic mature weight, B = degree of maturity at birth, K = maturing rate

Table 4 Means and SD of differences between predicted and actual body weights by growth period

Model	Early growth		Late growth		Maturity	
	Mean	SD	Mean	SD	Mean	SD
Quadratic	2.67	71.66	-1.64	75.43	7.53	62.99
Logistic	13.31	84.12	-0.51	76.26	11.84	67.74
Gompertz	-1.50	71.07	-3.59	76.31	7.09	62.32
Von Bertalanffy	0.45	71.07	-4.94	76.45	10.63	63.20
Brody	4.66	71.93	-11.39	76.69	18.06	66.15

Table 5 Coefficient of regression estimates for the Quadratic model by breed group

Breed group[a]	Coefficient of regression[b]					
	b_0	P-value	b_1	P-value	b_2	P-value
BG1	38.027 ± 5.159	0.0001	24.586 ± 0.289	0.0001	-0.174 ± 0.003	0.0001
BG2	38.481 ± 5.645	0.0001	24.956 ± 0.307	0.0001	-0.175 ± 0.003	0.0001
BG3	34.495 ± 11.024	0.0018	22.574 ± 0.549	0.0001	-0.143 ± 0.005	0.0001
BG4	23.923 ± 8.661	0.0059	24.538 ± 0.470	0.0001	-0.174 ± 0.004	0.0001

[a] BG1 = 0.96 ≤ H < 1.00, BG2 = 0.91 ≤ H < 0.96, BG3 = 0.86 ≤ H < 0.91, and BG4 = 0.44 ≤ H < 0.86

[b] b_0 = initial body weight, b_1 = linear regression coefficient, and b_2 = quadratic regression coefficient

Table 6 Means and SD of differences between predicted weights with the Quadratic model and actual weights in each growth period by breed group and total

Breed group[a]	Early growth		Late growth		Maturity	
	Means	SD	Means	SD	Means	SD
BG1	-1.97	71.39	-1.39	74.98	17.70	72.89
BG2	-6.28	58.27	-19.55	67.61	-5.71	49.01
BG3	23.78	99.57	27.47	83.45	-14.60	50.44
BG4	15.94	57.38	-3.48	68.13	38.44	60.69
Total	2.68	71.66	-1.64	75.43	7.53	62.98

[a] BG1 = 0.96 ≤ H < 1.00, BG2 = 0.91 ≤ H < 0.96, BG3 = 0.86 ≤ H < 0.91, and BG4 = 0.44 ≤ H < 0.86

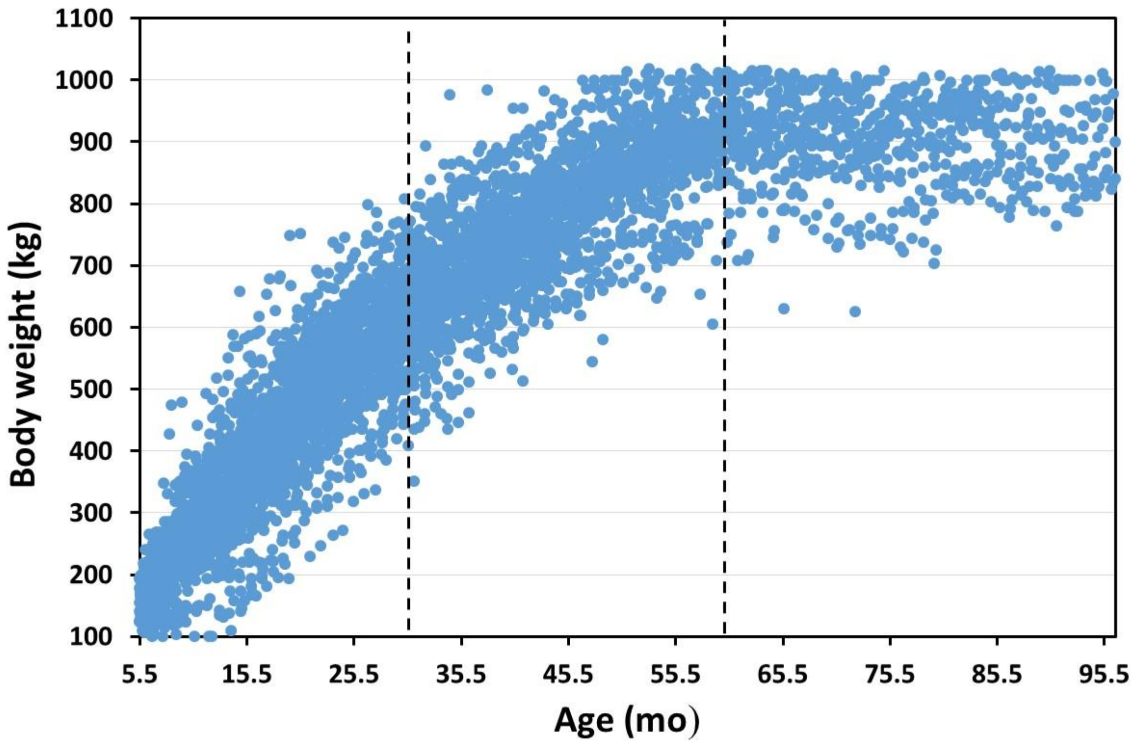

Fig. 1 Scatter plot of bull weights from 5.5 to 96 months of age

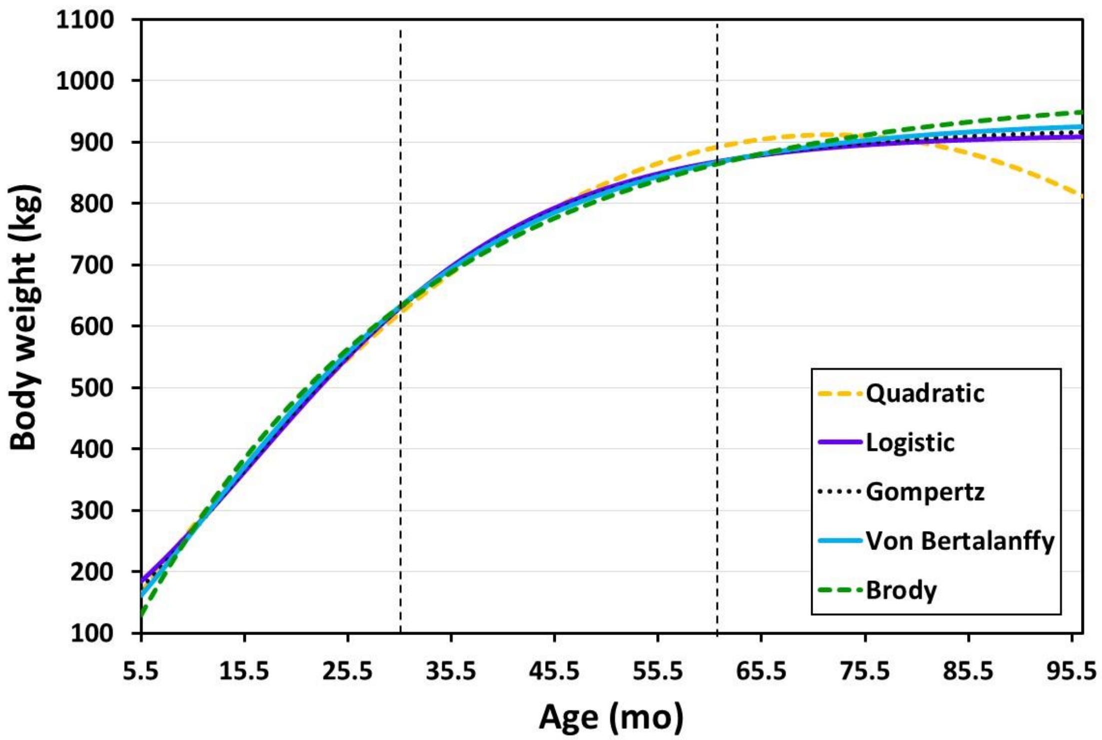

Fig. 2 Predicted growth curves between 5.5 and 96 mo of age using five growth models.

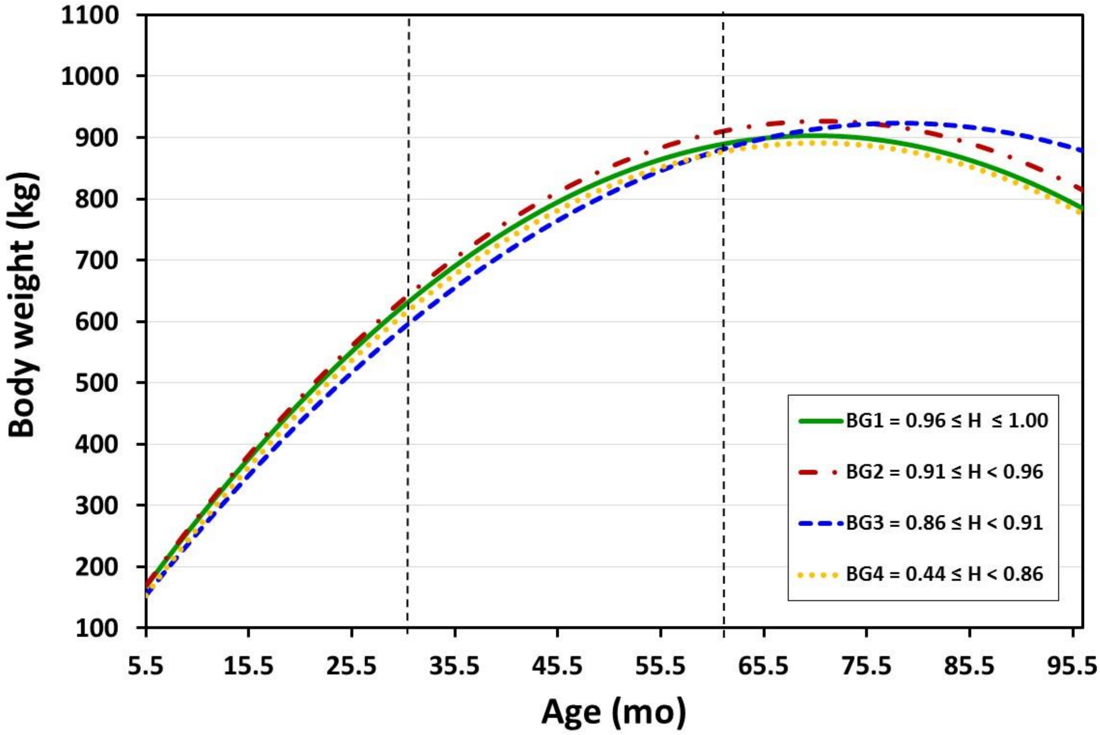

Fig. 3 Growth curves per breed group predicted using a Quadratic model.