Growth curves of developing Siboney females from Cuba, up to 18 months old

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Growth curves of 1,338 developing Siboney females from Cuba, between 0 and 18 months old, were modeled, in the period 2007-2009, with weights recorded at 0, 4, 8, 12 and 18 months. Curves were divided according to birth season, into rainy and dry seasons. Database was obtained from the information registered in SISCOP software for the studied years. Seven variants of regression models were tested (linear, square linear, cubic linear, square logarithmic, logistic, Gompertz and Richards), for data analysis, and daily weight gains were estimated through the method of square minimums. As statistical criteria for selecting the best adjusted model, the determination coefficient (R^2), parameters of models(α, β, γ, δ), mean square of error (MSE), standard error of models (E(α), E(β), E(γ)), E(δ)), model signification and residue analysis were determined. For females born during rainy season, the R^2 ranged between 0.94 and 0.97, while those born during dry season, the (R^2) ranged between 0.95 and 0.98. It can be concluded that the best adjusted model was the square logarithmic model, with con R^2 = 0.98 (born during dry season) and 0.96 (rainy season), with $P < 0.001$ in every case. The best increases were registered in animals born during dry season and between years. The best performance was registered in 2007

Key words: *mathematic models, growth curves, liveweight, bovines*

Cattle production is vital for sustenance and food safety of population, so that it can cover the requirements of 91 g of daily proteins per capita (González 2009), according to the gradual demand of animal origin products, needed by the country. This demand could be reached from efficient livestock production –under efficient and profitable bases- (Benítez *et al.* 2009).

Statistics informed from 2005 to 2010 show a sustained annual growth of milk production in Cuba (MINAG 2011). The Siboney breed from Cuba (5/8 H - 3/8 C) is one of the breeds used for these purposes because it has a wide distribution in the island, with 43.6 % of the total dairy cattle (Genética Nacional 2011), acceptable figures regarding the growth rates, besides an early incorporation with good levels of prolificacy (López 1983, López *et al.* 1986 and Gregorich 1992). The developing cattle is a continuity guarantee for keeping these productive increases.

Predicting and describing growth curves in bovines helps to characterize production systems and animal breeds. At the same time, it allows to provide useful information for developing selection strategies (Ramírez 2007). Duarte (1975), Elías (1998), Oliveira (2000) and Abreu *et al.* (2004) in South America, and Perotto *et al.* (1997) and Mazzini (2001) in Europe have worked on modeling growth of different breeds. In Cuba, studies like those of Fernández (2004), focused on lactancy curve modeling, and researches from Alonso (2009) in female bovines, up to 18 months old, have allowed to describe some factors that compromise the current performance of this breed in formation.

This study had the objective of estimating growth curves up to 18 months of age in Siboney females from Cuba, starting with the control weighing carried out at birth, at 4, 8, 12, and 18 months old, with the application of linear and non linear regression models, for 2007-2009.

Materials and Methods

A total of 1,338 records of females born between 2007 and 2009, from Siboney breed of Cuba were used in the U.E.B "Loma de Candelaria", belonging to the Empresa Pecuaria Genética "Camilo Cienfuegos". These records were obtained from a weighing gathered in the SISCOP program (Caunedo 1992) during the 0, 4, 8, 12 and 18 months.

The data extracted from the PVV. sgh, where all the weighings are located within the SISCOP databases, were organized per each year in Microsoft Excel. As a criterion for the statistical analysis per year, females were divided according to the season of their birth: 784 calves in dry season (from November 1st to May 14th) and 554 in rainy season (from May 15th to October 31st).

For analyzing and processing obtained data, four models of linear regression and three non linear regression models were tested. According to Ratkowsky (1983), these models are the most used for estimating animal behavior:

Linear models:

Linear: $y = alfa + beta\ (age)$

Square linear: $y = alfa + beta\ (age) + gamma\ (age)^2$

Cubic linear: $y = alfa + beta\ (age) + gamma\ (age)^2 + delta\ (age)^3$

Square logarithm: $\text{Log}\ y = alfa + beta\ (age) + gamma\ (age)^2$

Non-linear

Logistic: $y = \dfrac{alfa}{1 + beta.\exp[-\,gamma\ (age)]}$

Gompertz: y = *alfa. exp* <-*beta. exp* [-*gamma*(*edad*)]>
Richards: y = <*alfa*.[*1+beta. exp*(-*gamma*.{*edad*})]>

where:

y: LW or DWG

age: age of the animal

alfa (α), beta (β), gamma (γ) and delta (δ): parameters

Estimations for the parameters were determined by using the method of square minimums in the case of linear regression and by the iterative method of Marquardt (1963), for the non linear models (Logistic, Gompertz and Richards).

The statistical criteria for selecting better adjusted models were made according to indicators described by Guerra *et al.* (2002 and 2003) and Fernández (2004):

1. Determination Coefficient (R^2)
2. Parameters of models (α, β, γ, δ)
3. Mean square of error (MSE),
4. Standard error of model parameters SE(α), SE(β), SE(γ), SE(δ)
5. Model signification
6. Residue analysis

Compiled information was processed by the statistical package SPSS version 11.5.1 (2002).

Results and Discussion

Out of the evaluated models (linear, square linear, cubic linear, square logarithmic, logistic, Gompertz and Richards), those of non linear regression were rejected because they did not present a significant adjustment to LW.

Table 1, 2 and 3 show the results of the linear regression analysis for each season during 2007-2009. For a higher precision of the appropriate model in this type of study, an analysis of the exactitude along with the LW was made in each evaluated season per years, between 2007 and 2009.

When comparing the performance models of LW between seasons, during 2007, 2008 and 2009 (tables 1, 2, and 3), it was confirmed that all of them had a very good adjustment due to their flexibility (Arias *et al.* 2010), with similar and high determination coefficients (R^2), which indicates a good precision in the estimates. Besides, the use of linear models for describing growth of females from this breed was positive. All models differed (P < 0.001) in both seasons.

Values of R^2 were the best adjusted data, with 0.97, in the square logarithm for both seasons of 2007

Models estimating LW for females born in both studied seasons of 2008 differed at P < 0.001. There were low determination coefficients (0.94) in the linear and square linear adjustments, and during the rainy season.

As in 2007, the square logarithmic model of both seasons in which females were born was the best adjusted, with R^2 equals 0.96 during dry season and 0.97 during rainy season.

The same was confirmed in 2009 (P < 0.001) in the models evaluated for both seasons (table 3). For the females born during rainy season, the R^2 were lower,

Table 1. Results of model adjustment for each season of female birth, 2007

Model	Dry season N= 313							Rainy season N=183						
Parameters	α	β	γ	δ	R^2	MSE	Sign	α	β	γ	δ	R^2	MSE	Sign
Linear	38.13	11.61			0.95	292.19	***	35.5	12.54			0.95	306.68	***
SE (±)	0.95	0.09						0.74	0.07					
Parameter sign.	***	***						***	***					
Square linear	34.13	13.34	-0.09		0.95	281.47	***	34.43	13.0	-0.03		0.95	306.11	***
SE (±)	1.15	0.31	0.02					0.92	0.24	0.01				
Parameter sign.	***	***	***					***	***	***				
Cubic linear	33.49	13.34	-0.26	0.01	0.95	281.06	***	33.9	13.79	-0.15	-0.004	0.95	305.85	***
SE (±)	1.23	0.73	0.11	-0.004				0.98	0.57	0.08	-0.003			
Parameter sign.	***	***	*	ns				***	***	*	ns			
Square logarithmic	1.554	0.094	-0.003		0.97	0.03	***	1.56	0.09	-0.0026		0.97	0.0029	***
SE (±)	0.003	0.001	0.00004					0.0028	0.0007	0.00004				
Parameter sign.	***	***	***					***	***	***				

* P < 0.05 ***P < 0.001

Table 2. Results of model adjustment for each season of female birth, 2008

Model	Dry season N= 211							Rainy season N=206						
Parameters	α	β	γ	δ	R^2	CMe	Sign	α	β	γ	δ	R^2	CMe	Sign
Linear	31.54	11.58			0.95	304.1	***	37.1	11.06			0.94	283.17	***
SE (±)	0.91	0.09						0.87	0.08					
Parameter sign.	***	***						***	***					
Square linear	32.91	10.99	0.03		0.95	303.1	***	32.38	13.04	-0.11		0.94	268.92	***
SE (±)	1.12	0.09	0.02					1.05	0.27	0.01				
Parameter sign.	***	***	*					***	***	***				
Cubic linear	32.5	11.61	-0.06	0.003	0.95	303.1	***	32.34	13.09	-0.12	0.0003	0.95	267.17	***
SE (±)	1.2	0.7	0.1	0.003				1.12	0.66	0.09	0.003			
Parameter sign.	***	***	ns	ns				***	***	ns	ns			
Square logarithmic	1.53	0.09	0.002		0.96	0.003	***	1.54	0.09	-0.002		0.97	0.0027	***
SE (±)	0.003	0.001	0.00005					0.003	0.0008	0.00004				
Parameter sign.	***	***	***					***	***	***				

* P < 0.05 ***P < 0.001

Table 3. Results of model adjustment for each season of female birth, 2009

Model	Dry season N= 260							Rainy season N=165						
Parameters	α	β	γ	δ	R^2	CMe	Sign	α	β	γ	δ	R^2	CMe	Sign
Linear	36.61	11.84			0.96	209.02	***	33.29	12.39			0.94	412.9	***
SE (±)	0.85	0.08						0.94	0.09					
Parameter sign.	***	***						***	***					
Square linear	31.23	14.13	-0.13		0.97	268.92	***	32.24	12.83	-0.02		0.94	412.49	***
SE (±)	1	0.26	0.01					1.17	0.31	0.02				
Parameter sign.	***	***	***					***	***	ns				
Cubic linear	32.82	11.74	0.25	-0.01	0.97	185.79	***	30.47	15.5	-0.44	0.02	0.94	407.68	***
SE (±)	1.05	0.62	0.09	0.033				1.24	0.73	0.1	0.003			
Parameter sign.	***	***	**	***				***	***	***	***			
Square logarithmic	1.53	0.1	-0.002		0.98	0.0021	***	1.53	0.1	-0.0027		0.96	0.0042	***
SE (±)	0.0033	0.0008	0.00004					0.0037	0.0009	0.00005				
Parameter sign.	***	***	***					***	***	***				

** P < 0.01; *** P < 0.001

with 0.94 in all linear models, except in the square logarithmic model.

As in the previous years, the square logarithmic model, for both seasons of the year, had the best adjustment, with values of R^2 equals 0.98, in dry season, and 0.96 in rainy season.

According to Fitzhungh and Taylor (1971), selecting a specific model for describing growth will depend on its ability for biological interpretation and on the data adjustments and its requirements, regarding a computer program. Although during all the studied years the linear models had good adjustment of R^2 and $P < 0.001$, it is evident that the square logarithmic model was the best adjusted for LW of Siboney females from Cuba, from 2007 to 2009. The highest determination coefficients were found in this model, for all the years and seasons in which females were born, with a performance of $R^2 \geq 0.96$, mainly in 2007, for both seasons. These coefficients coincide with those informed by Brody (1945), cited by Fernández (1996), Molina *et al.* (1992) and Robert-Granié *et al.* (2002) in bovine growth curves. These authors consider that animal growth has a stage of linear growth. However, the adjustment of this model differs with the informed by Abreu *et al.* (2004), Pereda-Solís *et al.* (2005), Agudelo *et al.* (2007), Malhado *et al.* (2008) and Alonso (2009), who found a better adjustment in non linear models during the growth-development stage, with $R^2 \geq 0.90$. The previous data suggests further studies on the estimation of growth curves in this breed, with the use of other models.

For selecting the best adjusted model, the MSE is another statistical criterion to be considered. The square logarithmic model, for all years and seasons, had the lowest values, between 0.0021 and 0.03, inferior to those informed for the others. This allowed estimating, with higher precision, the effects of studied factors and, at the same time, selecting the best adjusted model for the analyzed cases.

The lowest values of MSE were registered in the group of animals born during rainy season, with 0.0029 and 0.0027, in 2007 and 2008, respectively. This indicates that there was a lower variance of liveweight, as the described by Freitas (2005), which explains the variability of this model in all years for this season of birth.

In addition, it can be considered, likewise, an expression of the use of feeding systems according to each growth stage and of the use of sustainable alternatives in livestock production, using a proper management of the grazing system during the ages in which the bovine is more efficient for pasture intake (Senra 2005 and Mejías 2008).

After adjusting the model, residues of the square logarithmic model were calculated. They were obtained from the comparison between LW observed and LW calculated using the selected model, for determining the existence of underestimation or overestimation of bovine LW (Fabens 1965). Regarding the criteria for the precision analysis of the estimations (residue analysis), figure 1a and b show the graphic performance of residues. Variation range of residues was between -0.1 and 0.1. The extreme values mostly corresponded to 2009, for those born during rainy season (-0.2 a 0.2). Figure 1 is essential to know the general performance of residues, according to Torres *et al.* (2012).

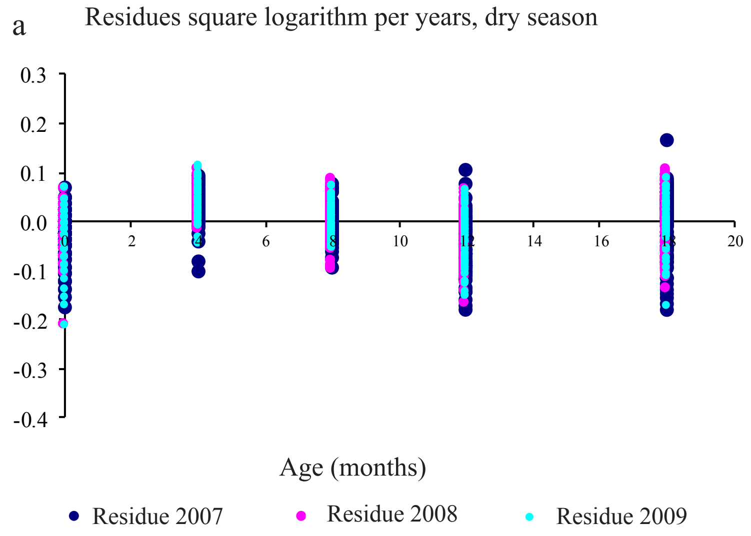
The best performance was shown by 2007. Female calves born in the dry season had the highest amount of residues, closed to -0.1 and 0.1.

For all the evaluated models, the α parameter indicates estimation of weight gain value reached by the animal (or the studied population), without being, necessarily, the highest weight the animal can reach, but the mean weight it gets when arriving to maturity, apart from the seasonal variations (Brown and bandermer 1997, Abreu *et al.* 2004 and Agudelo *et al.* 2007).

The analysis of α parameter, obtained through the square logarithmic model, shows that the highest value ranged between 1.55 and 1.56 ($P < 0.001$) for both seasons, every year. This is an indicator of development for achieving a bovine asymptotic weight. When comparing the estimations obtained from the four models, the highest value was achieved by the linear model and the females born in dry season (38.13 kg). The lowest value corresponded to the square logarithmic model (1.53 kg) in both seasons of 2009. Similar results were achieved by Oliveira *et al.* (2000), but in a narrower range. For the rest of the linear models evaluated in both seasons, the values of this parameter had a similar performance, between 31.5 and 37.1 kg, in both birth seasons of the studied females. There was an underestimation in the square logarithmic model from α parameter.

According to Freitas (2005) and Noguera *et al.* (2008), the β parameter does not have biological interpretation, but it is important for modeling the sigmoid curve from birth ($t=0$) to grown age ($t \rightarrow \infty$). Likewise, Abreu *et al.* (2004) state that this parameter is the integration factor that adjusts initial weight values, generally related to birth weight (development degree of the animal at birth for reaching the asymptotic weight). Nevertheless, its importance is considered for modeling the sigmoid curve, from birth to grown age, at 42 months old (Torres et. al 2012).

Abreu *et al.* (2004) and Marques da Silva *et al.* (2004) stated that γ is another important parameter for the study. It represents the maturity rate of animals, as a function between maximum growth rate and adult weight of the animal (growth speed). Torres *et al.* (2012) reported that animals with high values of γ represent an early maturity regarding those animals with similar initial weight. In the estimation of this parameter, the contrary to the asymptotic weight happened, with the estimations of considered models



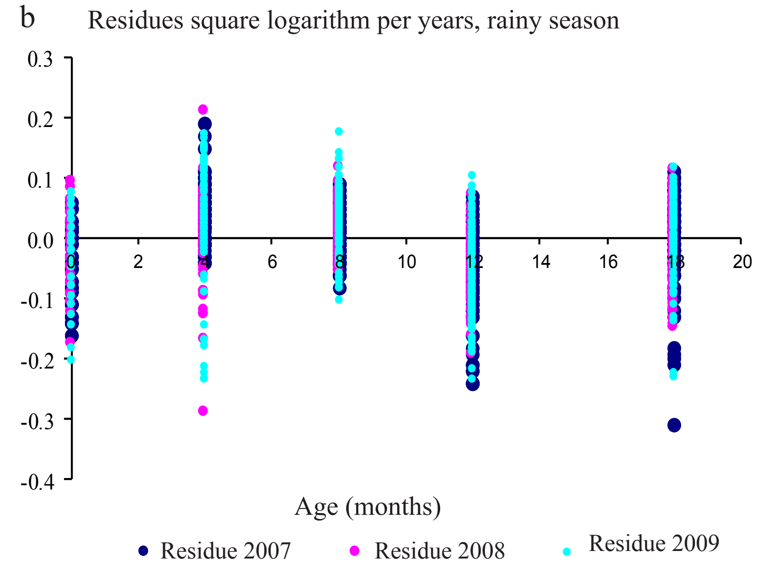


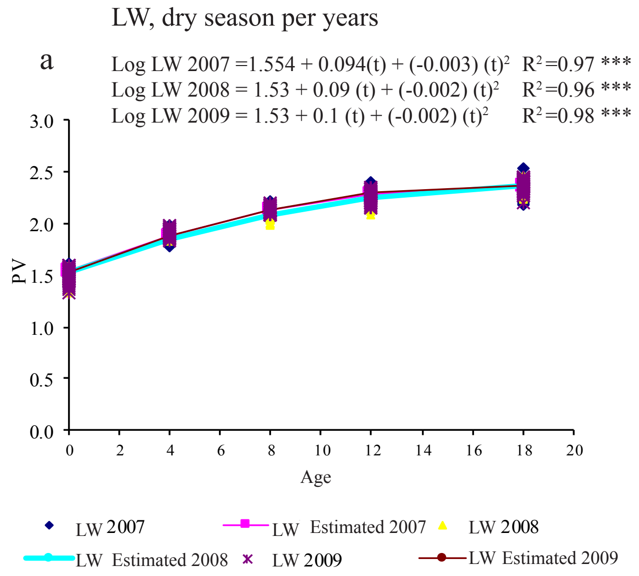
Figure 1a and b. Residue analysis of the square logarithmic model for the seasons studied between 2007 and 2009.

(-0.0027 a 0.27). Oliveira *et al.* (2000) informed similar performance in the estimations of this parameter in bovines, as well as Torres *et al.* (2012) inform it for crossbred Bufalypsos.

The square logarithmic model had, out of the four models, the best adjustment values of γ parameter, in both seasons and for all years, because its values (-0.0027- 0.002 and $P < 0.001$) and (-0.0026 – 0.002 and $P < 0.001$) in both seasons, respectively, were the lowest values compared to the rest of the models. This indicates a good precision of variations in the relative growth speed during both birth seasons. Besides, it also suggests stability in the growth rhythm, related to the favoring of mean daily gains of liveweight Marques da Silva *et al.* (2004), Malhado *et al.* (2008) and Torres *et al.* (2012) reported similar results but for non linear models adjusted to animal growth.

When analyzing results of mean performance among values of LW and the LW estimated using the square logarithmic model for each studied season from 2007 to 2009 in figure 1 a and b, there was a similar performance in the curve adjustment for each year and season, with a better increase in females born in dry season and in 2007, which confirms the correct selection of the model. Similar results when modeling growth were informed by Guerra *et al.* (1993), Fernández (1996), Del Valle (2000) and Guerra *et al.* (2003), who consider the good adjustment of linear models for expressing the standard growth curve of any living organism. There are no reports of studies, in the consulted literature, in which the square logarithmic model has the best adjustment for explaining the growth curve of developing bovine female.

According to Torres and Ortiz (2005), modeling and simulating can be applied to many problems related to ruminants, especially to the most studied category: milking cow. This study refers to the use of different models for describing a very important stage of bovine female, related to the increase of milk productions. According to Sampaio *et al.* (2005), using the better adjusted model, stochastic approximations can be made, which provide higher



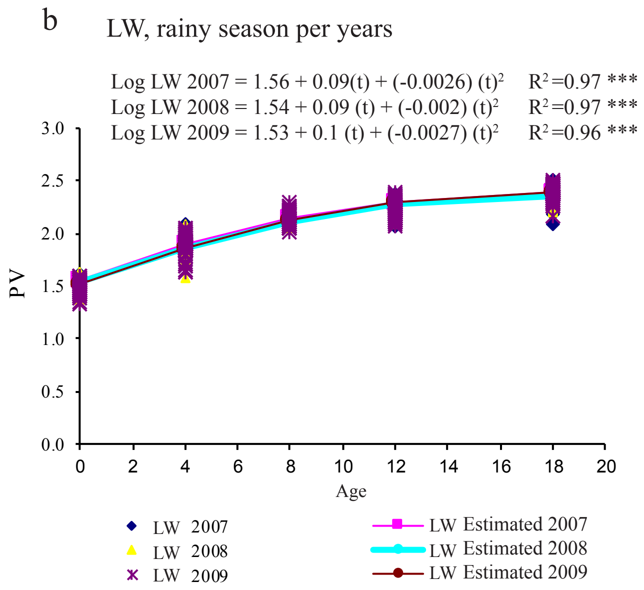


Figure 2 a and b. Performance of LW (kg) and mean LW, estimated through the square logarithmic model, per seasons and years, 2007-2009

information safety, and besides modeling parameters, they improve estimation levels. Similar arguments were informed by Fernández *et al.* (2001), Fundora *et al.* (2006) and Ramírez (2007).

It can be concluded that, among the studied models, the linear models showed a better adjustment for describing growth from 0 to 18, for Siboney breed from Cuba, in the Empresa Pecuaria "Camilo Cienfuegos". The square logarithmic model was highlighted, with $R^2 = 0.96$ and high signification, in the model and in α, β, γ, δ parameters evaluated. The best increases were registered in animals born during dry season. The best performance, among the years, was in 2007.

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