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Comparison of non-linear growth models to describe the growth curve in West African Dwarf sheep

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*The objectives of this study were to compare the goodness of fit of four non-linear growth models, i.e. Brody, Gompertz, Logistic and Von Bertalanffy, in West African Dwarf (WAD) sheep. A total of 5274 monthly weight records from birth up to 180 days of age from 889 lambs, collected during 2001 to 2004 in Betecoucou breeding farm in Benin were used. In the preliminary analysis, the General Linear Model Procedure of the Statistical Analysis Systems Institute was applied to the dataset to identify the significant effects of the sex of lamb (male and female), type of birth (single and twin), season of birth (rainy season and dry season), parity of dam (1, 2 and 3) and year of birth (2001, 2002, 2003 and 2004) on the observed birth weight and monthly weight up to 6 months of age. The models parameters (*A, B *and* k*), coefficient of determination (*R^2*), mean square error (MSE) were calculated using language of technical computing package Matlab®, 2006. The mean values of* A, B *and* k *were substituted into each model to calculate the corresponding Akaike's Information Criterion (AIC). Among the four growth functions, the Brody model has been selected for its accuracy of fit according to the higher* R^2*, lower MSE and AIC. Finally, the parameters* A, B *and* k *were adjusted in Matlab®, 2006 for the sex of lamb, year of birth, season of birth, birth type and the parity of ewe, providing a specific slope of the Brody growth curve. The results of this study suggest that Brody model can be useful for WAD sheep breeding in Betecoucou farm conditions through growth monitoring.*

Keywords: biological traits, non-linear models, West African Dwarf sheep, Benin

Introduction

The West African Dwarf (WAD) sheep (Rege, 1992) constitute the most important indigenous sheep breed found in the humid region of Africa, where trypanomosis and worm diseases impose a significant constraint. In Benin, the WAD sheep is raised exclusively for meat and was estimated at 700 000 (Faostat, 2005), and play an important economical, social and cultural roles. For this purpose in West and Central Africa, the genetic and non-genetic effects on the growth performance of WAD sheep had become an attractive study in last decades to improve overall productivity (London and Weniger, 1995; Yapi-Gnaoré *et al*., 1997; Gbangboche *et al*., 2006a and 2006b). However, the advantage of growth models such as Logistic and Gompertz (Renne *et al*., 2003; Lambe *et al*., 2006), Von Bertalanffy (Topal *et al*., 2004) and Brody model (Bathaei and Leroy, 1998), which give an explanation of what is biologically occurring during the growth phase of an animal, and their importance on breeding program (Varona *et al*., 1997; Lewis and Brotherstone, 2002) were unknown in WAD sheep. Therefore, model selection to predict typical growth in livestock industry, became a daunting task, given the broad range of criteria for goodness of fit, as the Akaike's Information Criteria (AIC) (Akaike, 1974), the coefficient of determination (R^2), the mean squares errors (MSE), the log-likelihood (lnL) values, and the least average prediction error (APE) (Brown *et al*., 1976; Goonewardene *et al*., 1981; Beltran *et al*., 1992; Lambe *et al*., 2006).

At least 800 head of WAD sheep were yearly maintained in the Bétécoucou breeding farm in Benin. Measuring the weight using spring balance becomes a long and difficult work due to the increasing number of animals. The knowledge of the adapted growth curves for WAD sheep in this farm should be helpful in determining proper management and in implementing selection decisions.

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Therefore, the objectives of this study were to compare the goodness of fit of non-linear function (Von Bertalanffy, Logistic, Gompertz and Brody) and to provide a specific shape of the growth curve according to the environmental effects on monthly weight from birth to 180 days of age in WAD sheep.

Material and methods

Animal and management

The WAD sheep is a small mature size hairy breed found all over West and Central Africa to the south of 14° latitude, and is widely distributed throughout the savannah and humid zones under tsetse-infested areas (Epstein, 1971; Rege, 1992). The WAD sheep is a compact breed with a short horizontal lop ears. The rams are horned and females usually polled. The coat color varied from spotted black and white to solid black or white. Mature size ranged from 40 to 60 cm at withers, mature weight from 20 to 30 kg for dams and from 25 to 35 kg for rams (Charray *et al*., 1992; Gatenby, 2002).

The Betecoucou breeding farm is situated in the Soudano–Guinean zone of Benin (between 2°20′ to 2°28′E longitude and 7°45′ to 7°52′N latitude) and was the reference center that provides superior animals to the sheep farmers. The year comprises two seasons: the rainy season from March to October and the dry season from November to February. The lambs are born during the year with a peak in rainy season. The new lambs were kept with their dam until weaning (90 days). Post-weaning male and female lambs grazed separately on the cultivated and natural pastures, and had no access to supplement other than that offered to the dams. The age at first lambing is between 430 and 838 days and the lambing interval, 190 and 544 days. The birth weight within 24 h of birth was taken using a platform type dial balance (10 kg capacity with 0.05 g accuracy). The weaning and post-weaning weights were recorded using a suspended spring balance (50 kg capacity with 200 g accuracy). The birth weight, weaning and 180-day weights were the criteria of selection. Management of the flock was described by Gbangboche *et al*. (2006a).

Data and preliminary environmental effect analysis

Monthly weights of WAD lambs from birth to 6 months (180 days) of age were provided by the Betecoucou breeding farm. The dataset consisted of 5274 records of 889 lambs, from year 2001 to 2004, born as single or double from 1st, 2nd and 3rd dams parity, during the dry and the raining seasons. The General Linear Model Procedure (proc GLM) of the Statistical Analysis Systems Institute (SAS, 2002–2003) was applied to the data to identify the significant effect of some environmental factors on the observed live body weight.

The fixed model used was:

$$Y_{ijklmn} = \mu + S_i + T_j + U_k + V_l + W_m + E_{ijklmn},$$

where Y_{ijklmn} is the adjusted weight of the *n*th lamb, μ is the overall mean, S_i is the fixed effect of the *i*th sex (i = male, female), T_j is the fixed effect of *j*th year of birth (j = 2001, 2002, 2003, 2004), U_k is the fixed effect of *k*th season of birth (k = dry season, rainy season), V_l is the effect fixed of *l*th birth type (l = single, twin), W_m is the effect fixed of *m*th parity ($m = 1, 2, 3$), E_{ijklmn} is the random error attributed to the *n*th lamb. Statistical differences between means were compared using Student's *t*-test. The number of observations, description of environmental factors and the least-squares means of live body weight are summarized in Table 1.

Models and goodness of fit

The Logistic, Gompertz, Von Bertalanffy and Brody functions were fit to the data to model the relationship between weight and age. The Logistic and Gompertz models have been described previously (Renne *et al*., 2003) for the Brody (Bathaei and Leroy, 1998) and for Von Bertalanffy (Topal *et al*., 2004). These models can be specified as:

Brody (exponential),

$$W_t = A(1 - Be^{-Kt}),$$

Gompertz (sigmoid),

$$W_t = A\ \exp(-Be^{-Kt}),$$

Logistic (sigmoid),

$$W_t = A/(1 + Be^{-Kt}),$$

Von Bertalanffy (sigmoid),

$$W_t = A(1 - Be^{-Kt})^3,$$

where W_t is the observed weight at age t expressed in months, and A is the asymptotic limit of the weight when age (t) approaches infinity. This does not imply that A is the heaviest weight attained by the individual, but it indicates the average weight of the mature sheep, independent of short-term fluctuation in weight due to temporary environmental effects. B indicates the proportion of the asymptotic mature weight to be gained after birth, established by the initial values of W and t. k is a function of the ratio of maximum growth rate to mature weight, normally referred to as maturing rate. It is related to postnatal rate of maturing and serves both as a measure of growth rate and rate of change in growth rate. Large k values indicate early maturing animals, and vice versa, e is Napier's base for natural logarithms, t is age expressed in day.

The language of technical computing package of Matlab®, 2006 was used to calculate the least-squares estimates ± standard error of the models parameters (A, B and k), the R^2, the MSE and the AIC. Details about the computing in Matlab®, 2006 are described in the Appendix.

Table 1 *Number of observations in parentheses (), least-squares mean ± standard error (LSM ± s.e.) of monthly weight from birth to 180 days of age, the level of significance of fixed effects, the coefficient of determination (R^2) and the coefficient of variation (CV) indicated by the proc GLM*

Fixed effect	BW (889)	W30 (864)	W60 (831)	W90 (778)	W120 (728)	W150 (594)	W180 (590)
Season of birth	**	**	*	**	**	ns	ns
Dry season (2420)	1.71 ± 0.02 (390)	3.82 ± 0.05 (380)	7.45 ± 0.06 (372)	10.67 ± 0.12 (352)	12.99 ± 0.14 (339)	14.65 ± 0.15 (295)	17.26 ± 0.18 (292)
Rainy season (2854)	2.14 ± 0.01 (499)	4.67 ± 0.04 (484)	7.75 ± 0.09 (459)	11.26 ± 0.09 (426)	14.15 ± 0.11 (389)	15.03 ± 0.13 (299)	17.34 ± 0.16 (298)
Year of birth	**	**	**	**	**	**	**
2001 (1046)	1.99 ± 0.02^d (176)	4.61 ± 0.08^b (176)	7.72 ± 0.15^c (166)	12.30 ± 0.16^a (162)	14.61 ± 0.19^a (151)	15.06 ± 0.23^b (108)	17.76 ± 0.28^a (107)
2002 (1548)	1.79 ± 0.01^c (228)	3.36 ± 0.06^d (225)	5.74 ± 0.12^d (223)	08.56 ± 0.12^d (221)	12.19 ± 0.14^d (217)	13.63 ± 0.15^d (217)	17.54 ± 0.18^b (217)
2003 (1450)	1.93 ± 0.01^b (248)	4.35 ± 0.06^c (229)	7.84 ± 0.11^b (229)	12.04 ± 0.13^c (192)	13.21 ± 0.16^c (185)	15.67 ± 0.16^a (185)	16.44 ± 0.20^c (182)
2004 (1230)	1.99 ± 0.01^a (237)	4.66 ± 0.07^a (234)	9.11 ± 0.14^a (213)	10.96 ± 0.15^b (203)	14.27 ± 0.20^b (175)	14.99 ± 0.27^c (084)	17.46 ± 0.33^d (084)
Type of birth	*	**	**	**	**	**	**
Twin (1918)	1.63 ± 0.01 (329)	3.90 ± 0.05 (312)	7.36 ± 0.10 (304)	10.60 ± 0.11 (278)	13.15 ± 0.14 (258)	14.26 ± 0.16 (220)	16.71 ± 0.19 (217)
Single (3356)	2.22 ± 0.03 (560)	4.60 ± 0.04 (552)	7.84 ± 0.07 (527)	11.33 ± 0.08 (500)	13.99 ± 0.10 (470)	15.43 ± 0.12 (374)	17.89 ± 0.15 (373)
Sex of lamb	*	*	**	**	**	**	**
Female (2560)	1.90 ± 0.01 (421)	4.17 ± 0.04 (408)	7.03 ± 0.09 (390)	10.52 ± 0.09 (372)	13.14 ± 0.12 (360)	14.36 ± 0.14 (306)	16.78 ± 0.17 (303)
Male (2714)	1.94 ± 0.01 (468)	4.32 ± 0.04 (456)	8.17 ± 0.08 (441)	11.41 ± 0.07 (406)	14.01 ± 0.11 (368)	15.32 ± 0.14 (288)	17.82 ± 0.15 (287)
Parity of dam	**	**	**	**	**	**	**
1 (2006)	1.56 ± 0.01^c (341)	3.24 ± 0.05^c (326)	7.06 ± 0.10^c (316)	10.19 ± 0.11^c (289)	12.28 ± 0.14^c (274)	13.53 ± 0.17^c (230)	16.55 ± 0.18^c (230)
2 (1880)	1.91 ± 0.03^b (320)	4.37 ± 0.05^b (314)	7.40 ± 0.10^b (296)	11.02 ± 0.09^b (277)	13.88 ± 0.13^b (257)	15.00 ± 0.16^b (209)	17.40 ± 0.19^b (207)
3 (1388)	2.31 ± 0.02^a (228)	5.13 ± 0.07^a (224)	8.34 ± 0.13^a (219)	11.69 ± 0.13^a (212)	14.56 ± 0.16^a (197)	15.99 ± 0.19^a (155)	17.95 ± 0.24^a (153)
R^2 of the model (%)	0.84	0.63	0.48	0.25	0.30	0.27	0.16
CV of the model (%)	12.17	21.84	22.90	16.10	15.48	15.2	15.61

BW, W30, W60, W90, W120, W150 and W180 were birth, 30, 60, 90, 120, 150 and 180 days weight, respectively. *$P \leqslant 0.01$; **$P < 0.001$. Within a column (and within each factor), values with different superscript letters differ significantly at $P < 0.05$.

The goodness of fit was assessed by using the higher R^2, the lower MSE and AIC values (Brown *et al.*, 1976; Akbas *et al.*, 1999; Topal *et al.*, 2004; Lambe *et al.*, 2006). Even though the selected models provide a view of the predicted weight at fixed age, the parameters *A*, *B* and *k* of the significant effect of season of birth, sex of the lamb, the parity of dam, the type of birth and the year of birth on the observed weight, have been calculated separately (Matlab®, 2006) simulating specific slop of the selected growth curve.

Result and discussion

Model parameters

The least-squares estimates parameters *A*, *B* and *k*, the R^2, the MSE and the AIC of the four competing models were reported (Table 2). The Figure 1 shows the pattern of each model from birth to 180 days of age: the Brody model was typically exponential (Figure 1a), while Gompertz (Figure 1b), Logistic (Figure 1c) and Von Bertalanffy (Figure 1d) models classically sigmoid. The parameter *A* was maximum in the Von Bertalanffy model (62.5 kg) and considerably less in Logistic model (31.0 kg). The estimate of B was smaller in the Von Bertalanffy (0.658 kg), while Gompertz (27.994 kg) showed greater values. The growth rate *k*, range from 0.0024 to 0.0174, showing the early maturity rate in Logistic model than other. When applying Brody growth function for the Mehraban Iranian fat tailed sheep, Bathaei and Leroy (1998) reported values 70.02, 0.95 and 0.1195 for *A*, *B* and *k*, respectively. Similar to this study, Brown *et al.* (1976), Goonewardene *et al.* (1981), Rogers *et al.* (1987) and Goliomytis *et al.* (2003) obtained different *A*, *B* and *k* values when fitting different growth functions to the same weight–age data indicating that the model of choice affects parameter estimates.

All competing models in this study had high R^2 from 0.82 to 0.84, suggesting overall good fits to the data. According to R^2 values models fall in the order Von Bertalanffy $>$ Gompertz $>$ Brody $>$ Logistic. The MSE value ranged from 0.0662 to 0.4557 and the Brody was ranked 1st according to the lowest MSE value. AIC values used to compare models, provide the following rank: Logistic $>$ Gompertz $>$ Von Bertalanffy $>$ Brody, implying that the Brody model had the least AIC value. Various R^2 and MSE values have been found in the literature, depending on the model applied, the structure of dataset and the species of animal. Higher R^2 values (0.98 to 0.99) and MSE (2.1 to 3.2) were reported for Morkaraman and Awassi lambs (Topal *et al.*, 2004). In the Scottish Blackface and Texel lambs, the value of R^2 ranged from 0.938 to 0.994 and AIC from 45.95 to 83.61 (Lambe *et al.*, 2006).

The goodness of fit

The Brody model showed the lowest MSE and AIC, and seems to be the best fit, even though its R^2 value was little less than in other models (Table 2). In previous studies, a broad range of models have been selected, depending on how accurately they fit the data. The Brody model has been similarly selected in cattle (Brown *et al.*, 1976; DeNise and Brinks, 1985; Doren *et al.*, 1989) due to its ability to accommodate missing growth points and converges easily (Kaps *et al.*, 1999). In the Bergamasca sheep in Brazil (McManus *et al.*, 2003), among the fitted growth models (Brody, Richards, and Logistic), the Logistic model showed the goodness of fit. Lambe *et al.* (2006) selected the Richards and Gompertz models for their accuracy of fit among four competing models (Gompertz, logistic, Richards and the exponential model). The Gompertz and Von Bertalanffy models showed the best fit in Morkaraman and Awassi lambs (Topal *et al.*, 2004); Gompertz model in Suffolk sheep (Lewis *et al.*, 2002). In fish population, the Gompertz model has been considered as the best fit according to AIC lowest value (Tsangridis and Filippousis, 1994; Imai *et al.*, 2002).

The predicted weight

Figure 1 contains the means of predicted *v.* observed monthly weights from birth up to 180 days of age according to each model. The observed minus predicted weight shows that the Brody model under predicted (Figure 1a) by −0.64 and −0.21 kg at 30 days and 60 days, respectively, and by −0.48 and −0.33 kg at 150 and 180 days weight, respectively. Inversely, the birth weight, 90 days and 120 days

Table 2 *Parameters estimates ± standard error, coefficient determination (*R^2*), mean square error (MSE) and Akaike's Information Criterion (AIC) of four models describing the growth curve in West African Dwarf sheep and the parameters related to the shape of the environment factors in the selected Brody model*

Models	Least-squares parameter				MSE	AIC
	A	*B*	*k*	R^2		
Gompertz	40.9 ± 2.08	27.994 ± 0.0084	0.0072 ± 0.0001	0.8415	0.1836	32893.4
Logistic	31.0 ± 2.27	11.115 ± 0.0210	0.0166 ± 0.0002	0.8212	0.4557	33408.6
Von Bertalanffy	62.5 ± 1.58	0.6588 ± 0.0045	0.0039 ± 0.0000	0.8462	0.0968	32889.0
Brody‡	46.9 ± 1.96	0.9620 ± 0.0030	0.0024 ± 0.0000	0.8215	0.0662	32395.1

‡Selected model: *A* is the predicted asymptotic weight at maturity (kg), *B* is the proportional difference between *A* and birth weight (kg) and *k* is the rate of maturating.

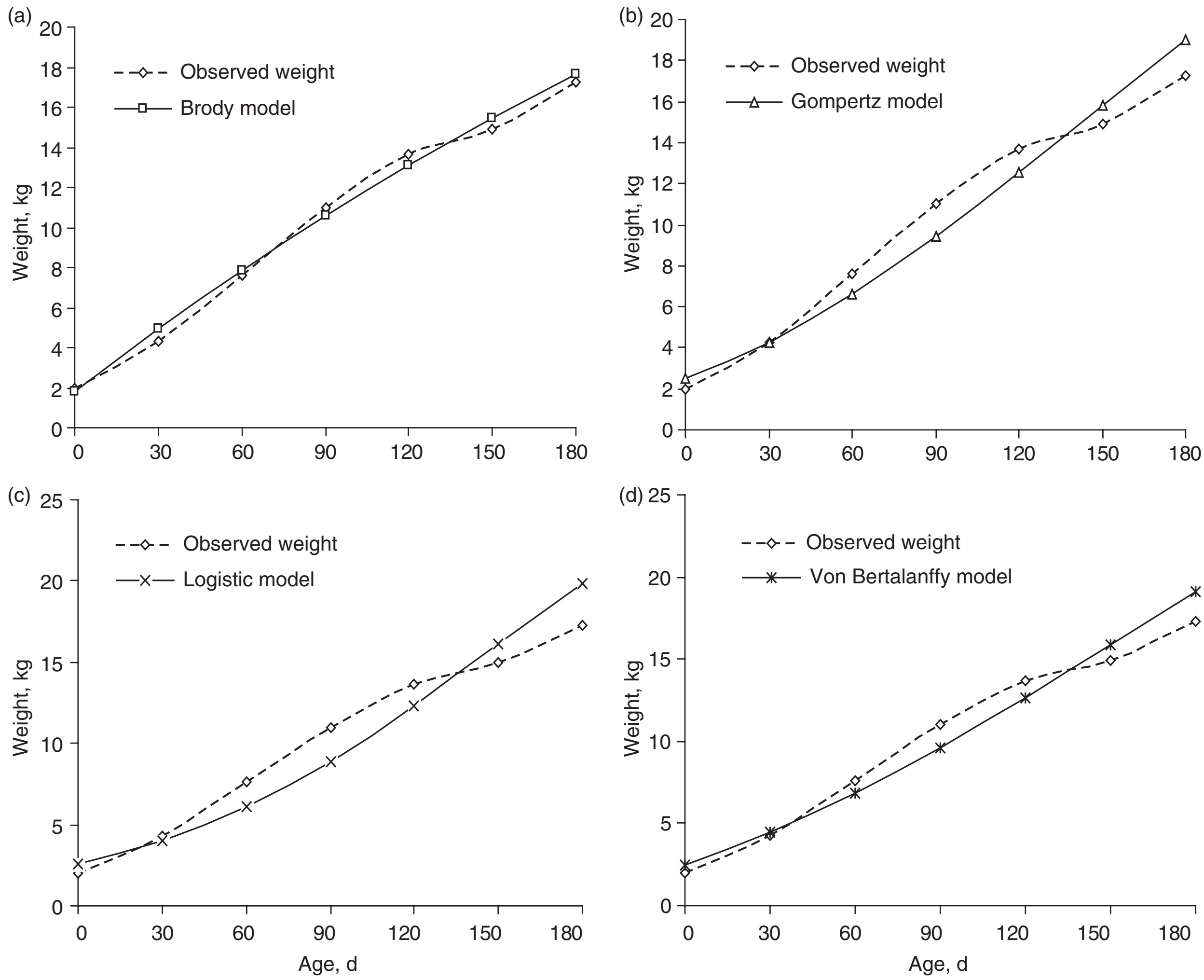

Figure 1 The shape of Brody (a), Gompertz (b), Logistic (c) and Von Bertalanffy (d) growth models *v.* observed monthly weight from birth to 180 days of age in West African Dwarf sheep.

weight were +0.2, +0.46 and +0.61 kg over predicted, respectively. Due to the paucity of literature on monthly weight in WAD sheep, a comparative study seems difficult. However, different growth weight of WAD sheep has been found in West Africa: 1.75 to 2.2 kg at birth (Armbruster *et al.*, 1991a and 1991b; London and Weniger, 1995; Yapi-Gnaoré *et al.*, 1997); 6.02 kg at 60 days of age (London and Weniger, 1995); 9.1 kg at 80 days of age (Yapi-Gnaoré *et al.*, 1997); 6.99 to 12.7 kg at 90 days of age (Poivey *et al.*, 1986; Armbruster *et al.*, 1991b; London and Weniger, 1995; Yapi-Gnaoré *et al.*, 1997); 8.71 kg at 120 days of age (Fall *et al.*, 1982); 15.1 kg at 180 days of age (Poivey *et al.*, 1986). Gbangboche *et al.* (2006a) reported the mean body weight of 27.5 ± 2.4 kg at 1.7 years, and London and Weniger (1995), 20.9 and 23.6 kg at 3.5 and 4 years of age. A minimum dam body weight of 11.0 kg was required for mating (London and Weniger, 1995). The fact that difference in management practices, levels of genetic improvement and many unknown factors affected WAD sheep may be explained by the variation in live body weight reported by many authors.

Environmental effect on the slope of the growth curve

The least-squares estimate parameters *A*, *B* and *k* are presented in Table 3 and Table 4, with the R^2, MSE and AIC values that rank the models related to the environmental factors. All models gave higher R^2, i.e. Von Bertalanffy (0.84 to 0.87), Gompertz (0.83 to 0.87), Logistic and Brody (0.80 to 0.85), suggesting their overall good fits to the data. The Brody model was ranked the first for AIC (205.27 to 2053.1) and MSE (0.06 to 0.07) and appears to be the best fitted even though its R^2 value was little less than in Von Bertalanffy and Gompertz models. Parameters among the environmental factors in Brody model ranged from 41.8 to 51.1, 0.9360 to 0.9841 and 0.0023 to 0.0025, respectively, for *A*, *B* and *k* (Table 3). The shape of the growth curve showed that male (Figure 2a) and single lambs (Figure 2b) were heavier than female and twin lambs, respectively. The higher weight of male than female has been described in WAD sheep (London and Weniger, 1995; Ebangi *et al.*, 1996; Gbangboche *et al.*, 2006b) and could be attributed to the hormonal and physiological differences between sexes (Ebangi *et al.*, 1996). The superiority of single lambs over

Table 3 *Parameters estimates ± standard error, coefficient determination* (R^2)*, mean square error (MSE) and Akaike's Information Criterion (AIC) of Brody and Gompertz models according to the environmental factors in West African Dwarf sheep*

	Models and parameters											
	Brody‡						Gompertz					
Environmental factors	*A*	*B*	*k*	R^2	MSE	AIC	*A*	*B*	*k*	R^2	MSE	AIC
Sex of lambs												
Male	47.1 ± 1.93	0.957 ± 0.0004	0.0025 ± 0.000	0.8235	0.0676	2009.9	39.8 ± 2.10	2.712 ± 0.0122	0.0075 ± 0.0001	0.8388	0.1915	3852.6
Female	45.5 ± 1.68	0.967 ± 0.0004	0.0024 ± 0.000	0.8359	0.0634	1424.4	40.1 ± 1.80	2.859 ± 0.0115	0.0072 ± 0.0001	0.8579	0.1729	4093.8
Type of birth												
Single	47.4 ± 1.93	0.957 ± 0.0004	0.0024 ± 0.000	0.8233	0.0665	2053.1	44.5 ± 2.00	2.767 ± 0.0098	0.0067 ± 0.0001	0.8459	0.1686	5295.7
Twin	43.7 ± 1.70	0.970 ± 0.0005	0.0025 ± 0.000	0.8410	0.0646	1228.4	35.1 ± 1.95	2.864 ± 0.0148	0.0081 ± 0.0001	0.8578	0.1946	2835.7
Season of birth												
Rainy season	47.8 ± 1.93	0.951 ± 0.0041	0.0024 ± 0.000	0.8127	0.0659	1759.3	45.3 ± 1.98	2.732 ± 0.0104	0.0065 ± 0.0001	0.8362	0.1682	4351.9
Dry season	45.7 ± 1.80	0.977 ± 0.0041	0.0025 ± 0.000	0.8458	0.0637	1790.9	38.8 ± 1.96	2.974 ± 0.0124	0.0078 ± 0.0001	0.8683	0.1796	4312.6
Parity of ewe												
Parity1	44.1 ± 1.70	0.978 ± 0.0046	0.0025 ± 0.000	0.8527	0.0613	1345.1	36.6 ± 1.87	2.992 ± 0.0133	0.0079 ± 0.0001	0.8742	0.1780	3464.4
Parity2	44.2 ± 1.84	0.957 ± 0.0049	0.0026 ± 0.000	0.8569	0.0633	1444.3	37.8 ± 1.98	2.664 ± 0.0130	0.0075 ± 0.0001	0.8727	0.1693	2302.2
Parity3	49.3 ± 1.89	0.945 ± 0.0062	0.0024 ± 0.000	0.8061	0.0683	936.99	51.1 ± 1.85	2.714 ± 0.0143	0.0060 ± 0.0001	0.8329	0.1579	2207.7
Year of birth												
2001	48.4 ± 1.75	0.973 ± 0.0063	0.0023 ± 0.000	0.8219	0.0612	553.18	43.7 ± 1.85	3.025 ± 0.0174	0.0071 ± 0.0002	0.8539	0.1691	2044.2
2002	51.1 ± 1.84	0.984 ± 0.0057	0.0023 ± 0.000	0.8237	0.0638	1054.5	58.4 ± 1.68	3.335 ± 0.0131	0.0062 ± 0.0001	0.8653	0.1460	3854.2
2003	41.8 ± 1.55	0.957 ± 0.0061	0.0028 ± 0.000	0.8508	0.0701	1069.1	34.8 ± 1.73	2.660 ± 0.0168	0.0080 ± 0.0002	0.8640	0.1923	1585.2
2004	45.7 ± 1.84	0.936 ± 0.0056	0.0025 ± 0.000	0.8244	0.0617	205.27	38.0 ± 2.00	2.441 ± 0.0160	0.0073 ± 0.0002	0.8346	0.1761	931.7

‡Selected model: *A* is the predicted asymptotic weight at maturity (kg), *B* is the proportional difference between *A* and birth weight (kg) and *k* is the rate of maturating.

Table 4 *Parameters estimates ±standard error, coefficient determination (R^2), mean squared error (MSE) and Akaike's Information Criterion (AIC) of Logistic and Von Bertalanffy models according to the environmental factors in West African Dwarf sheep*

	Models and parameters											
	Logistic						Von Bertalanffy					
Environmental factors	*A*	*B*	*k*	R^2	MSE	AIC	*A*	*B*	*k*	R^2	MSE	AIC
Sex of lambs												
Male	31.1 ± 2.25	10.48 ± 0.0295	0.0168 ± 0.000	0.8168	0.4646	7100.8	56.3 ± 1.73	0.64 ± 0.0068	0.0043 ± 0.000	0.8439	0.1069	2911.6
Female	27.6 ± 2.06	10.70 ± 0.0299	0.0174 ± 0.000	0.8401	0.4490	6233.4	64.1 ± 1.12	0.67 ± 0.0059	0.0037 ± 0.000	0.8624	0.0882	3425.9
Type of birth												
Single	31.6 ± 2.25	10.01 ± 0.0244	0.0160 ± 0.000	0.8319	0.4218	8460.1	70.1 ± 1.35	0.66 ± 0.0051	0.0035 ± 0.000	0.8492	0.0877	4411.6
Twin	26.7 ± 2.08	11.95 ± 0.0369	0.0186 ± 0.000	0.8358	0.4863	4956.4	50.7 ± 1.52	0.66 ± 0.0081	0.0045 ± 0.000	0.8628	0.1062	2188.3
Season of birth												
Rainy season	31.8 ± 2.25	9.62 ± 0.0262	0.0156 ± 0.000	0.8221	0.4241	6995.8	72.8 ± 1.30	0.65 ± 0.0053	0.0034 ± 0.000	0.8396	0.0863	3496.9
Dry season	28.6 ± 2.16	12.80 ± 0.0317	0.0183 ± 0.000	0.8484	0.4592	6727.7	60.0 ± 1.44	0.68 ± 0.0064	0.0041 ± 0.000	0.8726	0.0934	3658.0
Parity of ewe												
Parity1	26.7 ± 2.08	12.90 ± 0.0341	0.0188 ± 0.000	0.8550	0.4576	5387.7	55.8 ± 1.38	0.68 ± 0.0070	0.0042 ± 0.000	0.8784	0.0934	2837.2
Parity2	29.0 ± 2.16	9.65 ± 0.0310	0.0168 ± 0.000	0.8568	0.4040	4431.2	52.6 ± 1.63	0.63 ± 0.0074	0.0044 ± 0.000	0.8762	0.0964	1556.1
Parity3	33.4 ± 2.22	8.76 ± 0.0368	0.0150 ± 0.000	0.8220	0.4071	3290.4	88.3 ± 0.58	0.66 ± 0.0070	0.0030 ± 0.000	0.8356	0.0775	1925.3
Year of birth												
2001	29.4 ± 2.16	12.51 ± 0.0470	0.0178 ± 0.000	0.8362	0.4555	2909.7	79.0 ± 0.70	0.70 ± 0.0082	0.0034 ± 0.000	0.8581	0.0792	1870.0
2002	33.1 ± 2.22	14.31 ± 0.0386	0.0171 ± 0.000	0.8514	0.4293	4735.7	91.0 ± 0.00	0.72 ± 0.0067	0.0032 ± 0.000	0.8682	0.0746	3152.6
2003	25.2 ± 1.93	9.21 ± 0.0414	0.0184 ± 0.000	0.8469	0.4732	2936.3	49.0 ± 1.32	0.63 ± 0.0095	0.0046 ± 0.000	0.8683	0.1080	1346.4
2004	30.1 ± 2.16	8.01 ± 0.0373	0.0160 ± 0.000	08.010	0.4101	2536.8	49.6 ± 1.75	0.59 ± 0.0096	0.0045 ± 0.000	0.8392	0.1055	675.9

‡Selected model: *A* is the predicted asymptotic weight at maturity (kg), *B* is the proportional difference between *A* and birth weight (kg) and *k* is the rate of maturating.

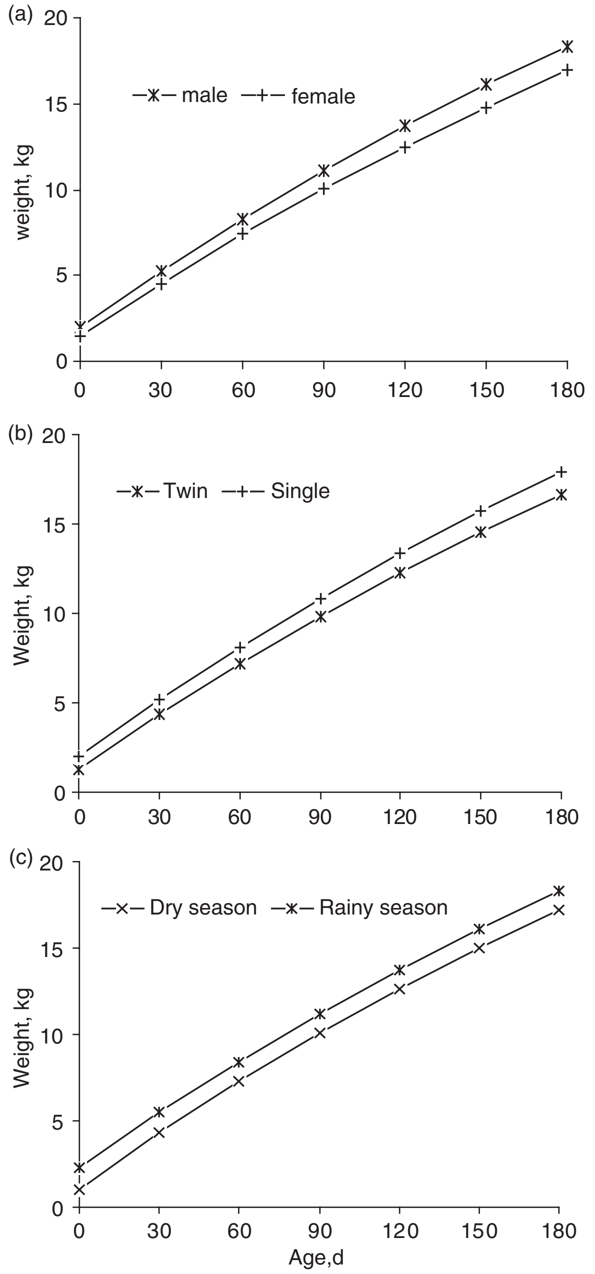

Figure 2 Slope of the selected Brody model according to the sex of lamb (a), type of birth (b) and season of birth (c) describing the growth in West African Dwarf sheep.

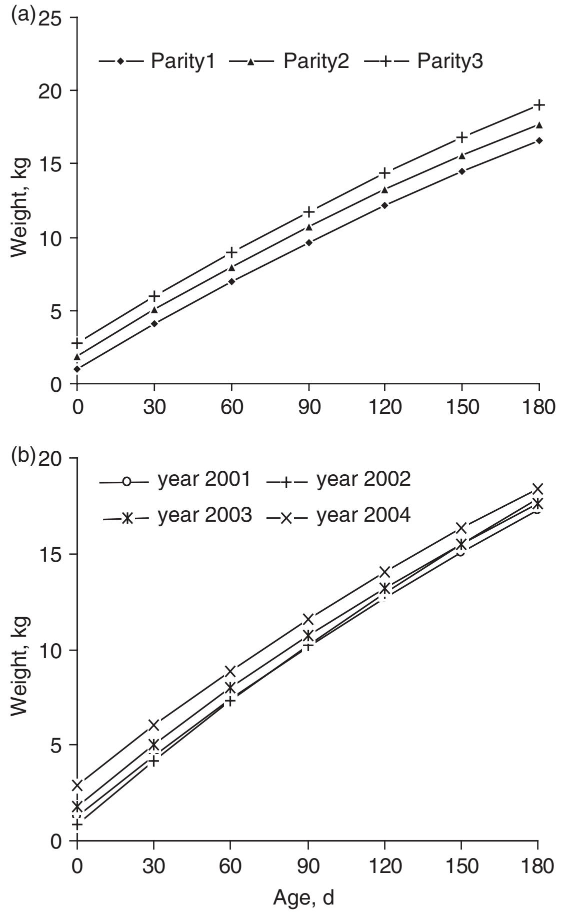

Figure 3 Slope of the selected Brody model according to the parity of ewe (a) and effect of year of birth (b) describing the lamb growth in West African Dwarf sheep.

the twins was similarly reported (Armbruster *et al.*, 1991a; Abassa *et al.*, 1992; Yapi-Gnaoré *et al.*, 1997) and in this case, the limited capacity of WAD dams to provide more nourishment for the development of multiple foetuses and more milk for new born lambs, could explain their low performance. The lambs born in rainy season were heavier and grew faster than their counterparts from the dry season (Figure 2c). Similar seasonal influences have been found in tropical area (London and Weniger, 1995; Ebangi *et al.*, 1996) and may be due to the variation of the physical environment that affect the availability and quality of forage during dry season, since the year-round grazing was the practice in Betecoucou farm. The lambs weight consistently increased with ewe parity (Figure 3a) as described in other studies (London and Weniger, 1995; Ebangi *et al.*, 1996; Yapi-Gnaoré *et al.*, 1997). The maternal effect (i.e. nursing, the bond between ewe and lamb) is more important with elder ewes, suggesting the advantages to have high-parity ewes in the flock. Indeed, the first-parity ewes are still growing, implying the competition for nutrient with the foetuses (London and Weniger, 1995). The incidence of year (Figure 3b) was reported in previous studies (Ebangi *et al.*, 1996 and Gbangboche *et al.*, 2006a and 2006b) and could be due to the changes during the year, in management, herdsman's skills and other environmental factors.

Conclusion

In WAD sheep, non-linear functions described the path by which this indigenous sheep travel from birth to 180 days of age. Divergent growth response was obtained and among the four models applied (Brody, Gompertz, Logistic and Von Bertalanffy), the Brody model provides the goodness of fit for the growth curve of WAD sheep in Betecoucou breeding farm. Consequently, Brody model would serve as valuable tools for overall productivity, feeding and drug administration, since this management is commonly focused on live body weight. Otherwise, this study showed the importance to adjust the model parameter *A*, *B* and *k*, when environmental factors affected significantly the observed weight, in order to provide a specific slope of growth curve: in this study the shape of growth curve due to the effect of year, season of birth, sex of lamb, type or birth, parity of dam have been built. However, it cannot be assumed that the Brody model could '*ad aeternam*' produce the goodness of fit in the Betecoucou breeding farm when the environmental conditions change. For this purpose, the model parameters need to be routinely re-adjusted, allowing even the possibility of testing all other non-linear growth models.

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Appendix

Computation of Brody, Gompertz, Logistic and Von Bertalanffy models in Matlab®, 2006.

```
function [note1,d,note2,da]=modele(y,x)
warning off;
[n,p]=size(x);
x=[ones(n,1),x];
z=max(y);
qs=(z+1:0.1:3*z+1)';
[n1,na]=size(qs);
for i=1:n1
   j=round(1+((qs(i)-z-1)/0.1));
   w1=log(1-(y/qs(i)));
   w2=log(log(qs(i)./y));
   w3=log((qs(i)./y)-1);
   w4=log(1-((y/qs(i)).^(1/3)));
   u1(j,:)=mode1(w1,x);
   u2(j,:)=mode1(w2,x);
   u3(j,:)=mode1(w3,x);
   u4(j,:)=mode1(w4,x);
end
[h1,h2]=size(u1);ua=(z+1:0.1:3*z+1)';wx=3*z+1;
l1=sortrows([ua,u1],4);la=l1(:,4);
la(1,:)=[];lb=l1(:,4);lb(h1,:)=[];q=la-lb;
b=0;
for i=1:h1-1
   if q(i)<0.0001
      ye(i,1)=i;
   b=b+1;
   end
end
ye(1:h1-1-b+5)=[];m1=l1(ye(1),:);
l2=sortrows([ua,u2],4);m2=l2(h1,:);
l3=sortrows([ua,u3],4);m3=l3(h1,:);
l4=sortrows([ua,u4],4);m4=l4(h1,:);
B1=exp(m1(1,2));B2=exp(m2(1,2));B3=exp(m3(1,2));
B4=exp(m4(1,2));
K1=-m1(1,3);K2=-m2(1,3);K3=-m3(1,3);K4=-m4(1,3);
A1=m1(1,1);A2=m2(1,1);A3=m3(1,1);A4=m4(1,1);
d1=[A1,B1,K1,m1(1,4),sqrt(m1(1,5))];
d2=[A2,B2,K2,m2(1,4),sqrt(m2(1,5))];
d3=[A3,B3,K3,m3(1,4),sqrt(m3(1,5))];
d4=[A4,B4,K4,m4(1,4),sqrt(m4(1,5))];
sw1=m1(1,1)*exp(m1(1,5));sw2=m2(1,1)*exp(m2(1,5));
sw3=m3(1,1)*exp(m3(1,5));sw4=m4(1,1)*exp(m4(1,5));
SCE=(n-1)*var(x(:,2));
xbar=mean(x(:,2));
ax1=1.96*sqrt(m1(1,5)*((1/n)+((xbar^2)/SCE)));
bx1=1.96*sqrt(m1(1,5)/SCE);
ax2=1.96*sqrt(m2(1,5)*((1/n)+((xbar^2)/SCE)));
bx2=1.96*sqrt(m2(1,5)/SCE);
ax3=1.96*sqrt(m3(1,5)*((1/n)+((xbar^2)/SCE)));
bx3=1.96*sqrt(m3(1,5)/SCE);
ax4=1.96*sqrt(m4(1,5)*((1/n)+((xbar^2)/SCE)));
bx4=1.96*sqrt(m4(1,5)/SCE);
Ba1=ax1;Ba2=ax2;Ba3=ax3;Ba4=ax4;
Ka1=bx1;Ka2=bx2;Ka3=bx3;Ka4=bx4;
[n1,h]=size((A1:wx)');[n2,h]=size((A2:wx)');
[n3,h]=size((A3:wx)');[n4,h]=size((A4:wx)');
Aa1=std((A1:wx)')/sqrt(n1);Aa2=std((A2:wx)')/sqrt(n2);
Aa3=std((A3:wx)')/sqrt(n3);Aa4=std((A4:wx)')/sqrt(n4);
da1=[Aa1,Ba1,Ka1];da2=[Aa2,Ba2,Ka2];
da3=[Aa3,Ba3,Ka3];da4=[Aa4,Ba4,Ka4];
note1=[' A ',' B ',' k ',' Rsq ',' MSE '];
note2=[' err(A) ',' err(B) ',' err(k) '];
d=[d1;d2;d3;d4]; da=[da1;da2;da3;da4];
x1=(1:360)';wt1=A1*(1-(B1*exp(-K1*x1)));
wt2=A2*exp(-B2*exp(-K2*x1));
wt3=A3./(1+B3*exp(-K3*x1));
wt4=A4.*((1-B4*exp(-K4*x1)).^3);
plot(x1,wt1,'-',x1,wt2,'-',x1,wt3,'-',x1,wt4,'-');
axis([0,180,0,30]);
legend('Brody','Gompertz','Logistic','Von Bertalanfly',2);
xlabel('Age, d')
ylabel('Weight, kg')
```