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Technical note

Growth curves in purebred and crossbred Limousin cattle

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Abstract:

The objective was to fit a non-linear model (NLM) to evaluate the growth curve in purebred (PB) Limousin cattle and in five degrees of crossbreeding (DCBs: 1/2, 3/4, 7/8, 15/16, 31/32 Limousin). Live weight, the birth weight interval at 500 d of age, was analyzed. Four NLMs were evaluated: Brody, Bertalanffy, Gompertz, and logistic. Growth parameters were estimated: adult weight (ADW); growth rate (GR); age (AIP; months) and weight (WIP; kg) at inflection point; age (months; A50M) to reach 50 % maturity and degree of maturity at 15 mo (DM15). The growth curve in DCB was characterized using the NLM selected for BP. The best-fitting model was Bertalanffy. The ADW for purebred (PB) males was 566.1, for crossbred (CB) males it was in the range of 446.9 to 527.4; for CB females it was in the range of 374.5 to 419.9, and for PB females, it was 443.0. The NLMs exhibited correlations below -0.75 between ADW and GR. In PB heifers, AIP was estimated at 3.7, and WIP, at 131.2; in CB heifers, AIP and WIP were in the ranges of 2.9 to 3.7 and 110.9 to 124.4, respectively. A50M for PB females was 10.6, and for CB females, within the range of 8.9 to 10.5. DM15 for CB females, the average was 90.5 %, and 87.9 % for PB females. PB males reach A50M at the age of 13 mo.

Key words: *Bos Taurus*, Crossover, Growth parameters, Heterosis, Nonlinear models.

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The Limousin breed, originated in France as a pure breed or in crossbreeding schemes[1,2] has productive, reproductive, and adaptive qualities that have allowed its distribution in a large number of countries and production systems[3,4,5]; it has also been used in the development of synthetic breeds[6]. It arrived in Mexico through imports from Canada and the United States in the 1970s; the Mexican Association of Limousin Cattle Breeders (AMCGL, in Spanish) was established in 1989[7,8]. It is currently distributed in 17 states, especially as a pure breed, although it is also used in open crossbreeding schemes and as a basis for the makeup of synthetic breeds, such as Limousan (5/8 Limousin and 3/8 Angus)[9] and Brahmousin (5/8 Limousin and 3/8 Brahman)[10].

The AMCGL coordinates the genealogical record of breed purity and purity degrees, as well as the production records that define the breed selection criteria and objectives[7]. Productive data associated with growth include live weight at birth and at 120, 210, and 365 d of age, with measurements at the plus or minus 45-d interval of the specified age. Live weight measurements generate a distribution of observations throughout the life of the animal, which together can be used to characterize and evaluate the growth curve. Non-linear models (NLM) characterize and analyze the animal growth curve based on the biological interpretation and applications of the regression coefficients, as well as growth parameters derived from the regression coefficients[11,12,13]. Regression coefficients and growth parameters play an important role in decision making for management, nutrition, breeding, and genetic improvement programs[14,15,16,17]. Based on the above, the objective of the present study was the selection and adjustment of a NLM to describe and evaluate the growth curve in Limousin cattle from Mexico.

The database consisted of live weight measurements in the weight interval from birth to 500 d of age in Limousin cattle (PB; purebred). In order to define the growth curve, four NLMs were evaluated: Brody (BRO), von Bertalanffy (BER), Gompertz (GOM), and logistic (LOG), all of which are made up of three regression coefficients (β1, β2, and β3)[12,13,18]. In the NLM equations (Table 1), ***yi*** represents the live weight (kg) measured at time ***t***; β1, is the asymptotic value when ***t*** tends to infinity, interpreted as the adult weight parameter (AWP); β2, is an adjustment parameter when $y \neq 0$ and $t \neq 0$; and β3, is the growth rate (GR), expressing weight gain as a proportion of total weight. The BER, GOM, and LOG models are characterized by describing growth based on a sigmoid curve, for which age (AIP; months) and weight (WIP; kg) at the inflection point were calculated. The BRO model exhibits a growth curve with a constant GR and no inflection point. The regression coefficients were used to estimate the age at 50 % maturity (A50M), the degree maturity attained at 15 months (A15M) of age[19,20], as well as the correlation (r_{ac}) between GR and ADW.

Table 1: Nonlinear models evaluated in purebred and crossbred Limousin cattle

Model	Equation
Logistic	$y_i = \beta_1 / (1 + \beta_2*(exp(-\beta_3*t))) + e_i$
Bertalanffy	$y_i = \beta_1*((1 - \beta_2*(exp(-\beta_3*t)))**3) + e_i$
Gompertz	$y_i = \beta_1*(exp(-\beta_2*(exp(-\beta_3*t)))) + e_i$
Brody	$y_i = \beta_1*(1 - \beta_2*(exp(-\beta_3*t))) + e_i$

y_i= live weight in kg, measured at time t; β_1= asymptotic value; β_2= integration constant; β_3= slope of the growth rate curve.

Analyses were performed for each sex, using the Gauss-Newton method of the NLIN procedure of the SAS statistical analysis software[21]. The selection of the best-fitting model was based on[18,19]: Akaike information criterion [AIC= n*nl(sse/n) + 2k]; Bayesian information criterion [BIC= n*nl(sse/n) + k*nl(n)]; coefficient of determination [R^2= (1 - (sse/tss))]; and, overall standard error or model (OSE= $\sqrt{\frac{sse}{n-p-1}}$. Where: n = total number of data; sse= sum of squares of the error; tss = total sum of squares; k= number of parameters in the model; nl = natural logarithm. For AIC and BIC, the model with the lowest value was considered the best fit.

The AMCGL managed a herd register with various degrees of purity (DCB) for the purpose of increasing the Limousin cattle population through absorbing crossbreeding, based on crossbred cows and PB sires. With the model selected as the best fit in the PB population, the growth curve was characterized in populations defined by five DCB or generations: first (D1) with ½ Limousin; second (D2) with ¾ Limousin; third (D3) with 7/8 Limousin; fourth (D4) with 15/16 Limousin; and, fifth (D5) with 31/32 Limousin. Table 2 describes the database analyzed in terms of BP and DCB.

Table 2: Live weight database, analyzed across genetic and sex groups, with measurements from birth to 500 d of age

Sex / Group	D1	D2	D3	D4	D5	Purity
Males	1963	1489	1607	3428	6224	31784
Females	2220	2296	2449	4784	7382	35695

Genetic groups: PG, 1/2 Limousin; SG, 3/4 Limousin; TG, 7/8 Limousin; CG, 15/16 Limousin; QG, 31/32 Limousin. Breed purity ($\geq$ 63/64 Limousin).

In model selection, within sex with AIC and across sex with BIC, the best fitting model was BER, followed by BRO and GOM; in all models the R^2 was greater than 95 % (Table 3). Table 4 shows the results for the regression coefficients and product growth parameters of the evaluated NLMs. ADW estimation was higher for PB *vs* CB, in contrast, the GR was higher in CB. The genetic improvement scheme for Limousin cattle in Mexico includes weaning weights adjusted to 205 d[7], with potential significance in the growth curves, given that the inflection point is located in the pre-weaning period. The BRO model was second in the model ranking; however, it exhibited outlier results for ADW, A50M and DM15. All models had a r_{ac} below -0.75 (Table 4), which indicates that high ADWs do not derive from high GRs. Figure 1 for males and Figure 2 for females depicts the growth based on the BER model for all genotypes evaluated.

Table 3: Statistics used for selection of the best-fit nonlinear model

Statistics	Brody	Gompertz	Logistic	Bertalanffy
Males				
R^2	96.7	96.7	96.6	96.7
OSE	40.3	40.3	40.9	40.3
AIC	236935.8	237022.3	237856.6	236896.4
BIC	236960.9	237047.5	237881.7	236921.2

Females				
R^2	96.8	96.8	96.7	96.8
OSE	35.6	35.7	36.1	35.6
AIC	255208.7	255253.0	256169.4	255127.7
BIC	255234.2	255278.4	256194.9	255153.1

AIC= Akaike information criterion; BIC= Bayesian information criterion; R^{2}= coefficient of determination; OSE= overall or model standard error.

Table 4: Regression coefficients and growth parameters derived from nonlinear models evaluated in purebred and crossbred Limousin cattle

item	β_1	β_2	β_3	r_{ac}	AIP	WIP	A50M	DM15
Purebred males with all the evaluated nonlinear models								
Brody	1645.9	0.9778	0.000618	-0.99	--	--	36.2	26.0
Gompertz	491.0	2.5475	0.00583	-0.92	5.3	180.6	7.4	83.1
Logistic	408.2	8.8538	0.0117	-0.76	6.2	204.1	6.2	98.5
Bertalanffy	566.1	0.5949	0.00400	-0.96	4.8	167.7	13.0	81.2
Purebred females with all evaluated nonlinear models								
Brody	715.1	0.9508	0.00151	-0.99	--	--	14.2	51.8
Gompertz	402.9	2.396	0.00656	-0.90	4.4	148.2	6.3	88.2
Logistic	352.3	8.0113	0.0124	-0.71	5.6	176.1	5.6	99.1
Bertalanffy	443.0	0.5666	0.00477	-0.95	3.7	131.2	10.6	87.9
Males in degree of purity with Bertalanffy model								
D1	527.4	0.5896	0.00394	-0.97	4.8	156.3	13.1	80.7
D2	522.4	0.5858	0.00418	-0.96	4.5	154.8	12.3	83.0
D3	514.5	0.5876	0.00410	-0.96	4.6	152.4	12.6	82.3
D4	446.9	0.5705	0.00481	-0.95	3.7	132.4	10.5	88.1
D5	467.1	0.5724	0.00469	-0.96	3.8	138.4	10.8	87.3
Females in degrees of purity with the Bertalanffy model								
D1	391.4	0.5563	0.00511	-0.94	3.3	115.9	9.7	90.0

D2	374.5	0.5446	0.00563	-0.94	2.9	110.9	8.7	92.6
D3	419.9	0.5619	0.00476	-0.95	3.7	124.4	10.5	87.9
D4	399.2	0.5572	0.00509	-0.95	3.4	118.3	9.8	89.9
D5	379.9	0.5471	0.00551	-0.94	3.0	112.5	8.9	92.1

Degrees of purity: D1, 1/2 Limousin; D2, 3/4 Limousin; D3, 7/8 Limousin; D4, 15/16 Limousin; D5, 31/32 Limousin. Regression coefficients: β_1, β_2, and β_3. Where: β_1 is the asymptotic value, interpreted as the adult weight parameter; β_2 is an adjustment parameter, and β_3 is the growth rate, expressing weight gain as a proportion of total weight. Age (AIP; months) and weight (WIP; kg) at the inflection point. A50M, age at 50 % of maturity. DM15, degree of maturity (%) at 15 months of age. r_{ac}, correlation between β_1 and β_3.

Figure 1: Growth curves for Limousin males. Purity, purebred animals; D1, 1/2 Limousin; D2, 3/4 Limousin; D3, 7/8 Limousin; D4, 15/16 Limousin; D5, 31/32 Limousin

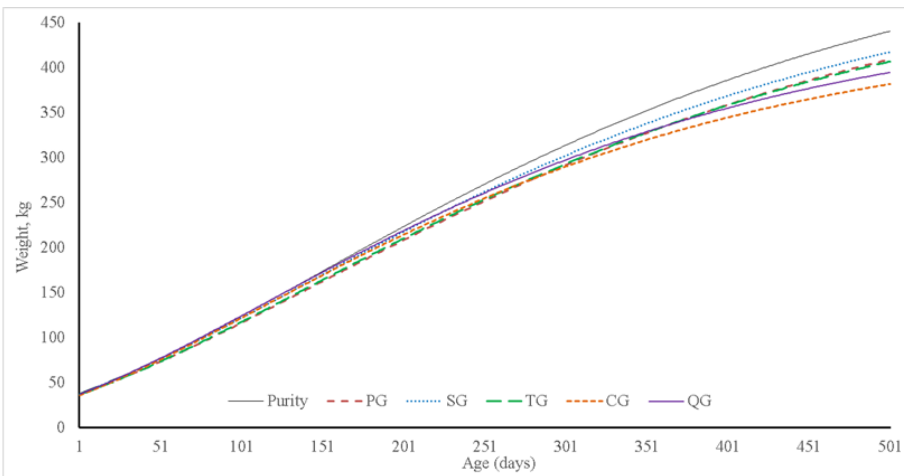
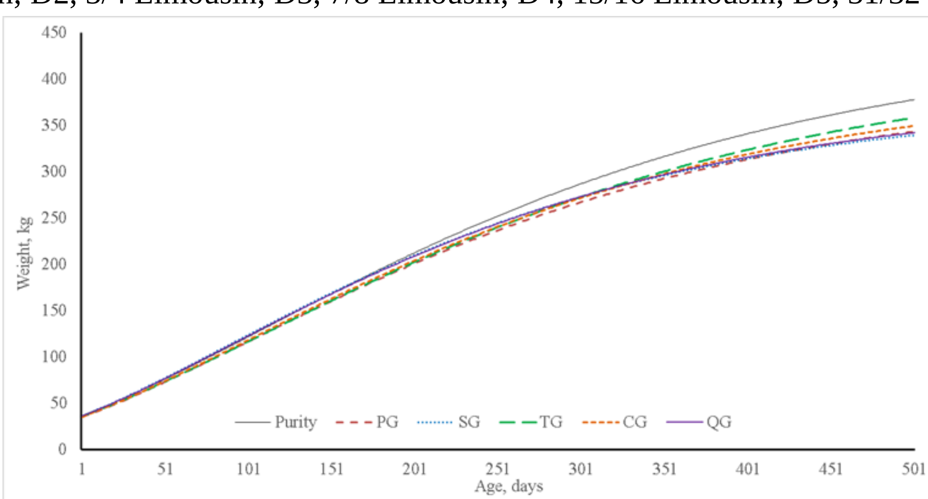


Figure 2: Growth curves for Limousin females. Purity, purebred animals; D1, 1/2 Limousin; D2, 3/4 Limousin; D3, 7/8 Limousin; D4, 15/16 Limousin; D5, 31/32 Limousin



In purebred Limousin cattle with three different production systems, Igarzabal *et al*[3] reported GOM as the best fitting model. In crossbreeding schemes of Limousin with Angus, Hereford, and MARC III, Zimmermann *et al*[17] used the BRO model to characterize the growth curve and evaluate live weight at maturity; in Limousin x Friesian cattle, they represented growth based on the GOM model[22]. In the Madrasin breed, product of the crossbreeding of Limousin with Madura, the growth described a sigmoid type curve, characterized with the LOG model[23]. Growth curves evaluated with the BER model were reported in Holstein[24], Pyrenean, and Blonde cattle[3].

In Mexico, several studies have discussed contrasts in the type of growth curve across breeds. For growth curves without an inflection point, in five zebu breeds in tropical cattle ranching, Domínguez-Viveros *et al*[25] reported that the best fitting NLMs were Brody, Meloum III and Mitscherlich; the BRO model in particular was selected as the one with the best fit in Romosinuano cows[20], as well as in Tropicarne[19] and Salers cattle[26]. For sigmoid growth curves, Contreras *et al*[27] in Jersey, Holstein, and Jersey-Holstein crossbred cows, the selected MNLs were GOM, LOG, and BER, respectively; the BER model has been reported for Hereford cattle[26].

The incorporation of replacement heifers at the reproductive phase is of transcendence for the genetic progress and profitability of the herd. This procedure is carried out in three stages[28]: at the onset of pituitary maturation, triggered at a certain age and weight; followed by the development of the ovaries and body growth; maturation of the uterus as a consequence of pituitary development and its hormonal influence on body growth and ovarian activity, allowing the heifer to mate and develop gestation. Several studies have analyzed the influence of growth parameters on reproductive variables[20,24,29]; Thus, the inflection point has been associated[13,30,31] with the onset of the reproductive phase. Age at first calving is an indicator of the time it takes for an animal to reach sexual maturity and reproduce for the first time, and mating at approximately 15 mo, with age at first calving of approximately 24 mo, has positive effects on cow longevity and productivity[32,33]. Based on the BER model, differences are observed in CB *vs* PB females for the components of the growth curve (Table 4), which can be attributed to genetic differences across breeds and heterosis effects resulting from the crossing scheme. In PB heifers, AIP was estimated at 3.7 mo with a WIP of 131.2 kg; in CB, AIP and WIP were in the ranges of 2.9 to 3.7 mo and 110.9 to 124.4 kg, with average values of 3.3 and 116.4, respectively. A50M in females, was estimated to be at 10.6 mo in PB, and within the range of 8.9 to 10.5 mo for CB, with an average value of 9.5 months. For DM15 in females, the average value was 90.5 % for CB, while the estimate for PB was 87.9 %. In contrast, among females from other populations and based on the BER model: Contreras *et al*[27] for Holstein, Jersey and crossbreds estimated AIP (months) and WIP (kg) in the ranges of 7.4 to 9.8 and 115.0 to 151.7, respectively; in five zebu breeds, Domínguez-Viveros *et al*[25] reported AIP and WIP estimates in the ranges of 3.9 to 11.7 and 107.2 to 230.9, respectively; in Romosinuano[20], Tropicarne[19], and Siboney[29]. AIP - WIP results were 15.5 - 132.5, 7.7 - 180.5 and 5.9 - 152.4, respectively.

As for the males, the selection of stallions is carried out among PB, and they are incorporated for reproduction from one year of age; however, lowering the age of entry into reproduction reduces the generation gap and has an impact on genetic progress[34]. The growth curve can influence the development of the reproductive phase; in *Bos taurus* breeds, the physiological events associated with reproduction begin at six to eight months; maturity and reproductive capacity are determined by the quality of the semen, with variations due to the effects of live weight, growth rate, scrotal circumference, among other factors[35]. The results indicate that PB males reach 50 % maturity at 13 mo of age, with values above 80 % at 15 mo of age (Table 4). In contrast[26], Hereford and Salers cattle reported maturity levels of 68.2 % and 76.6 % at one year, respectively. On the other hand, growth curve indicators are associated with profitability in production; the GR has an effect on age and slaughter weight; degree of maturity is important for efficiency and carcass composition[16,22]. Various authors[15,36,37] have assessed the differences and derivations of the growth curve in relation to production for purebred males and various crosses.

The best fitting model was von Bertalanffy, which described a sigmoid growth curve, with differences in growth parameters across the evaluated genotypes. Tipping point estimates are within the context of pre-weaning growth.

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