Mathematical functions for the prediction of growth in Indian dromedary genotypes

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Mathematical functions for the prediction of growth in Indian dromedary genotypes

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ABSTRACT

Growth of Bikaneri, Jaisalmeri, Kachchhi and Arabcross (Arab×Bikaneri) camels from birth to 20 years of age was analyzed for the year 1984 to 2005. The average annual body weights in the Indian dromedary were recorded as 37.1±0.3, 208.6±2.2, 269.1±3.5, 346.1±4.3, 403.4±4.3, 460.2±6.6, 510.2±7.4, 541.8±7.7, 569.8±8.3, 576.0±9.0, 575.9±9.4, 585.7±9.8, 569.8±9.6, 571.0±11.2, 566.5±11.2, 569.7±12.4, 547.6±12.3, 576.2±13.9, 569.8±16.6, 558.9±16.6 and 548.0±18.4 kg, respectively from birth to 20 years of age. The male sex was differentiated from the female sex at 24 months of age but the genetic groups were nonsignificantly different from each other except the Arabcross camels at some stages. It was observed that the camels attain their adult weight at 8 years of age but the growth phase continues up to 11 years of age. The linear, quadratic, cubic, exponential and Gompertz functions were derived to explain the age-weight relationship in Indian dromedary genotypes and the respective R^2 values were 0.661, 0.964, 0.994, 0.45 and 0.967. It is quite evident from the analysis that the cubic function explains the growth of camel for the entire life time to the extent of 99.4%, hence the cubic equation $Y = 73.2592 + 9.9072X - 0.0631X^2 + 0.000128 X^3$ can be utilized for the estimation of body weight of camels of different sexes and genetic groups.

Key words: Camel, Cubic, Gompertz, Growth, Mathematical functions, Regression

Growth of an animal can be considered as an index of its production potential and reproductive performance. The body weight of an animal plays a significant role in selection experiments and in deciding the dose of medication during treatment. The camels of four years and above age were considered as adults and their body weights were considered as adult body weights (National Research Centre on Camel, 1991–92, 1998–99 and 1999–2000, Khanna *et al*. 2004). Beniwal and Chaudhary (1983) studied the growth pattern in the Bikaneri camel *(Camelus dromedarius)* from birth to 30 months of age and developed a function explaining the growth during this period. Xue Hue-Wei and Zhao Xing-Xu (1999) studied the live weight growth of neonate bactrian camel *(Camelus bactrianus)* up to 14 months of age. Further, the growth phase in animals has been designated as non linear and the Gompertz curve has been documented to explain the population and growth in animals (Snedecor and Cochran 1994). However, the growth phase analysis expanding over the entire life span of the camels and proper mathematical function to explain the body weight gain in camels have not been documented so far. Therefore, a critical analysis of growth of camels belonging to different sexes and breeds of Indian dromedary from birth to 20 years of age was planned and 4 mathematical functions were tried to explain the age-weight relationship in camel.

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MATERIALS AND METHODS

The data belonging to Bikaneri, Jaisalmeri, Kachchhi breeds and Arabcross (Arab×Bikaneri) camels maintained at the National Research Centre on Camel, Bikaner, India from the year 1984 to 2005 was analyzed. All animals were measured from birth to the day last in the herd or up to 20 years of age. Care was taken to weigh the animals before they were sent out for grazing. Pregnant females and sick animals were avoided. Animals receiving special feed, fodder or attention due to their allotment to different experiments were excluded from the herd and hence not measured. Pregnant females after calving and sick animals after recovery were measured. Animals considered absolutely normal after experimentation were taken back in the herd and measured, and rest were culled. From birth to 36 months of age, the weights were taken at an interval of 3 months and thereafter annual weights till 20 years of age were considered for analysis.

Statistical analysis: The least squares analysis of variance was carried out to study the effect of breed, sex and year on body weight (Harvey 1987). The breed and age group means were compared using Duncan's multiple range test (Duncan 1957). The linear, quadratic, cubic, exponential and Gompertz functions (SPSS 10.0 and Croxton *et al*. 1969) were derived using following equations –

Linear : $Y = b_0 + b_1x$

Quadratic : $Y= b_0 + b_1x + b_2x^2$

Cubic : $Y = b_0 + [b_1x] + [b_2x^2] + [b_3x^3]$

Exponential : $Y=b_0b_1^{(b_2^x)}$ or $\ln [Y] = \ln b_0 + b_2^x[\ln b_1]$

Gompertz : $Y=b_0 e^{(b_1^x)}$ or $\ln [Y] = \ln [b_0] + [b_1x]$

where, Y is body weight in kg, x- is age in months or years, b_0 is a constant and b_i are coefficients of the predictor variables.

RESULTS AND DISCUSSION

The average body weights in the 2 sexes and the 4 genotypes of Indian dromedary, viz. Bikaneri, Jaisalmeri, Kachchhi and Arabcross from birth to 20 years of age were analysed. The birth weight in the Bikaneri, Jaisalmeri, Kachchhi and Arabcross camels were 37.6±0.4, 36.9±0.5, 36.4±0.9 and 35.5±1.9 kg, respectively. The adults of the above 4 genetic groups weighed 599.1±17.0, 594.6±15.0, 553.3±21.1 and 595.0±9.0 kg, respectively, at 11 years of age. The examination of the body weight trend (Table 1) clearly indicated that the growth in camels continued up to 11 years of age when the average body weight of camels reached to a maximum of 585.7±9.8 kg. The attainment of highest average weight in each of the 4 genetic groups and the 2 sexes was observed separately and it was found that from 8 to 11 years of age the camels attain their highest average body weights.

Mathematical functions to explain the growth pattern in the camel right from birth to 20 years of age were derived. The linear, quadratic, cubic, exponential and Gompertz curves were initially fitted on body weight data taken at a uniform interval of one year till 17 years of age, as the data

Table 1. Average body weight (±SE) in the 2 sexes and 4 genetic groups of Indian dromedary

(body weight in kg)

Age	Male	Female	Bikaneri	Jaisalmeri	Kachchhi	Arabcross
Birth	37.1±0.4 (127)*	37.1±0.4 (162)	37.6±0.4 (137)	36.9±0.5 (96)	36.4±0.9 (43)	35.5±1.9 (13)
3 months	82.0±1.9 (105)*	88.4±1.8 (141)	87.6±1.9 (116)	84.9±2.1 (85)	82.6±3.9 (34)	81.1±6.7 (11)
6 months	143.0±2.9 (73)**	152.0±2.4 (112)	147.9±2.7 (88)	151.5±3.1 (65)	146.4±5.0 (26)	132.3±5.8 (6)
9 months	187.2±3.1 (71)	179.4±2.7 (105)	180.3±2.9 (89)	187.6±3.3 (55)	185.0±5.5 (24)	165.3±13.9 (8)
12 months	211.1±3.5 (87)	206.8±2.7 (125)	210.0±3.0 (105)	211.7±3.4 (72)	203.3±5.9 (24)	185.6±14.6 (11)
15 months	235.0±3.8 (96)	227.5±3.2 (126)	228.4±3.6[a] (99)	236.2±3.9 [a] (78)	235.0±5.5 [a] (34)	201.1±16.3[b] (11)
18 months	242.7±5.6 (62)	237.1±3.8 (100)	239.4±4.5[a] (75)	245.2±5.3 [a] (58)	243.7±6.7 [a] (21)	183.3±14.2 [b] (8)
21 months	261.4±5.8 (48)	254.6±4.4 (87)	256.7±4.3[a] (67)	263.9±5.7 [a] (46)	262.5±10.9 [a] (17)	179.6±14.9 [b] (5)
24 months	267.3±6.3 (62)	270.2±4.1 (95)	265.3±4.7 [a] (75)	277.7±5.9 [a] (61)	273.2±10.6 [a] (15)	218.7±14.3 [b] (6)
27 months	302.7±7.1 (55)	287.2±4.3 (93)	287.7±5.5 [a] (72)	302.2±6.2 [a] (50)	300.3±9.1 [a] (21)	245.4±22.0 [b] (5)
30 months	317.8±7.9 (50)	298.0±5.8 (80)	303.2±7.3 (61)	306.4±8.3 (43)	317.3±9.4 (15)	300.0±18.0 (11)
33 months	328.2±10.3 (38)	320.5±5.5 (73)	325.8±7.9 (47)	325.5±8.5 (41)	318.8±11.1 (17)	298.0±23.1 (6)
3 years	349.0±7.7 (57)	344.5±5.1 (97)	345.9±6.1 (66)	348.0±6.5 (63)	343.8±11.1 (16)	339.1±31.5 (9)
4 years	408.9±7.4 (59)	400.5±5.2 (113)	409.9±6.1 (79)	405.3±7.5 (64)	383.9±9.4 (20)	376.1±18.0 (9)
5 years	469.5±11.9 (34)	456.1±8.0 (78)	467.9±10.9 (44)	457.4±10.8 (43)	461.6±12.7 (22)	376.0±30.1 (3)
6 years	545.8±11.1 (36)**	488.4±8.8 (59)	508.8±12.5 [a] (36)	527.7±12.3[a] (38)	492.4±10.8 [a] (18)	411.3±0.7 [b] (3)
7 years	581.6±9.7 (42)**	509.6±9.3 (52)	531.7±12.4[a,b] (34)	569.5±10.8[a] (38)	516.1±17.2[a,b] (18)	479.0±45.1 [b] (4)
8 years	614.3±10.3 (48)**	528.7±10.0 (52)	548.3±15.1[a,b] (31)	598.0±12.6[a] (43)	558.7±13.8[a,b] (21)	508.0±41.4 [b] (5)
9 years	638.3±10.3 (41)**	526.8±9.3 (52)	567.8±18.4 (30)	596.0±11.7 (38)	558.6±20.3 (19)	544.7±31.9 (6)
10 years	636.5±11.6 (30)**	541.6±10.6 (53)	574.7±18.2 (30)	595.8±14.1 (33)	548.5±15.4 (16)	530.5±28.2 (4)
11 years	644.7±15.4 (23)**	551.8±9.2 (40)	599.1±17.0 (22)	594.6±15.0 (23)	553.3±21.1 (16)	595.0±9.0 (2)
12 years	622.5±20.3 (21)**	549.3±9.5 (54)	594.5±13.2 (31)	559.5±14.9 (26)	533.3±31.8 (12)	560.3±33.6 (6)
13 years	635.7±21.1 (15)**	547.9±11.4 (42)	581.2±16.7 (22)	566.3±17.9 (20)	556.5±41.9 (8)	569.4±34.1 (7)
14 years	648.4±18.7 (9)**	550.4±11.6 (46)	584.8±14.4 (26)	546.8±21.5 (17)	500.0±54.7 (4)	581.8±28.0 (8)
15 years	645.2±17.8 (5)*	560.3±13.1 (40)	581.2±16.4 (20)	555.6±23.6 (15)	542.7±64.1 (3)	578.9±35.4 (7)
16 years	609.6±28.1 (5)	538.9±13.0 (36)	548.0±15.3 (23)	541.8±32.1 (9)	541.0±62.8 (4)	561.2±18.8 (5)
17 years	647.3±45.8 (3)	568.9±14.1 (29)	596.8±19.4 (18)	552.2±23.3 (10)	470.0±0.0 (1)	568.0±17.2 (3)
18 years	651.6±38.6 (5)*	552.8±16.7 (24)	596.9±22.3 (15)	535.6±26.6 (12)	NA	572.0±20.0 (2)
19 years	716.0±0.0 (1)*	551.4±15.5 (21)	582.4±31.3 (10)	536.4±17.3 (10)	554.0±22.0 (2)	NA
20 years	654.7±43.8 (3)**	523.4±13.3 (13)	541.6±26.7 (10)	598.7±21.7 (3)	518.7±23.3 (3)	NA

* (P<0.05); ** (P<0.01); figures with different superscripts differ significantly (P<0.05); NA- Not available; figures in parenthesis show number of observations.

Table 2. Regression models, R^2 values and constants for the prediction of body weight in different models, breeds and sexes

Model	Breed/sex	R^2	b_o	b_1	b_2	b_3
Linear	Pooled	0.661	266.587	24.0912		
Quadratic	Pooled	0.964	106.557	84.1023	–3.5301	
Gompertz	Pooled	0.967	566.832	0.059125	0.494564	
Cubic	Pooled	0.994	56.4445	125.494	–9.7941	0.2457
Exponential	Pooled	0.450	202.706	0.0844		
Cubic	Bikaneri	0.993	75.9396	9.6501	–0.0600	0.000121
Cubic	Jaisalmeri	0.990	71.4556	10.2883	–0.0652	0.000127
Cubic	Kachchhi	0.986	78.7486	9.5559	–0.0604	0.000116
Cubic	Arabcross	0.985	73.7315	7.6061	–0.0376	0.000060
Cubic	Male	0.993	71.7684	9.9951	–0.0568	0.000104
Cubic	Female	0.994	77.1550	9.6433	–0.0656	0.000147
Cubic	Pooled	0.994	73.2592	9.9072	–0.0631	0.000128

in some of the genetic groups was not available in later age groups. The R^2 values obtained were 0.661, 0.964, 0.994, 0.45 and 0.967, respectively in linear, quadratic, cubic, exponential and Gompertz functions (Table 2). The quadratic, gompertz and cubic functions explained the variability to >96% but the predicted values (Table 3) indicated that cubic can reliably be considered as the best tool to explain the growth of camels at any stage during the life time. The cubic functions were, therefore, derived utilizing the full set of data i.e. body weights at 3 months interval from birth to 3 years of age and annual weights thereafter till 20 years of age, for the 4 genetic groups and the 2 sexes (Table 2).

Sexual dimorphism: The data revealed that the superiority of male sex over female sex was quite fluctuating till 2 years of age. The males dominated thereafter till 20 years of age. However, statistically significant differences in the body weights in the 2 sexes were observed only after 5 years of age till 15 years of age. The sex effect was nonsignificant at 16 and 17 years of age and significant from 18 to 20 years of age. This shift in the effect of sex after 15 years of age can very well be accounted for the availability of very few males as compared to the females (Table 1).

Table 3. Predicted body weights by the Gompertz, quadratic and cubic regressions vis-à-vis observed body weights of Indian dromedary

Age (in years)	Observed body weights (Y)	Predicted body weights (Y)		
		Gompertz	Cubic	Quadratic
0	37.09	33.51	56.44	106.5571
1	208.56	139.96	172.39	187.1293
2	269.09	283.82	270.22	260.6414
3	346.14	402.61	351.41	327.0933
4	403.37	478.60	417.44	386.4851
5	460.16	521.33	469.77	438.8168
6	510.19	543.85	509.89	484.0884
7	541.76	555.35	539.27	522.2998
8	569.80	561.12	559.37	553.4511
9	575.97	564.00	571.68	577.5423
10	575.88	565.43	577.67	594.5733
11	585.73	566.14	578.82	604.5443
12	569.83	566.48	576.59	607.4551
13	570.98	566.66	572.47	603.3057
14	566.45	566.75	567.92	592.0963
15	569.73	566.79	564.42	573.8267
16	547.56	566.81	563.45	548.497
17	576.22	566.82	566.47	516.1071

The dromedary male gives successful service at 5–6 years of age, and it can be used for regular breeding after 6 years of age, whereas a female dromedary can be conceived at an age of 4 years (Khanna *et al*. 1987). This indicates that the sex hormones start playing their role at this stage in camel and hence they influence the body weights in the two sexes differently as has been observed in the present investigation.

Breed polymorphism: The present investigation did not support the literature (Rathore 1986, Khanna *et al*. 2004) that the Bikaneri is the heaviest breed of camel (Table 1). Statistically, the effect of breed on body weight of camels was significant from 15 months' age to 27 months' age and from 6 years' age to 8 years' age. Further analysis using mean separation indicated that, at all of the above stages of age, the 3 Indian dromedary breeds differed nonsignificantly but the fourth genetic group i.e. Arabcross (Arab × Bikaneri) camels differed significantly from rest of the breeds. This could probably be due to the availability of less number of camels in the group or real breed differences due to the inheritance of Arab genes or both. Beniwal and Chaudhary (1983) reported relatively higher body weights for Bikaneri breed from birth to 30 months of age. However, Khanna *et al*. (1990) reported relatively lower values of the body weights from birth to 3 years of age for Jaisalmeri breed and higher values for the Bikaneri, Kachchhi and Arabcross camels. Further, while analyzing 5-year data from the 1985 to 1990, Khanna *et al*. (2004) reported slightly higher values than the present observations for all the genetic groups including the Jaisalmeri breed from birth to 3 years of age and the camels of 4 years and above age were considered as adults.

Non-genetic factors: The camel breeds during the winter and its gestation length is of 13 months. The calving also takes place in winter. All animals in the herd were born during the same season. The year of birth was considered as a factor affecting the growth of camels in the herd but it was observed that the effect of year was significant only at the time of birth and it was nonsignificant for rest of the stages. This finding is supported by the fact that the camels are least affected by the environmental changes and inhabit the most difficult lands of the world most reasonably due to their unique adaptive mechanism (Yagil 1985).

Growth phase: The growth of camels belonging to the 4 genetic groups and the 2 sexes was analyzed. Mathematically, the mean separation indicated that the subsequent body weights were quite different from their preceding body weights till 8 years of age only. The critical examination of the data indicated that the growth of the camels continued beyond 8 years till 11 years of age and thereafter a static or declining trend was observed. This indicated that the camels attain their adult weight at 8 years of age but the growth phase continues up to 11 years of age (Table 1). This is in contrast to the published reports that the camels attain their adult body weight at 4 years of age (NRCC, 1991–92, 1998–99 and 1999–2000, Khanna *et al*. 2004).

Mathematical functions: Gompertz, quadratic and cubic functions explained the growth of camels for the entire life time to >96% extent. The cubic function explained the variability to the extent of 99.4% and the predicted values were very close to the observed values (Table 3). It was considered as the best tool to explain the growth of camels at any stage during the life time. The cubic functions were, therefore, derived utilizing the full set of data for the 4 genetic groups and the 2 sexes along with the one for the entire species (Table 2). These regression equations can be utilized for the prediction of body weight at any age of camel. The accuracy of prediction was calculated to be more than 98.5%. Hassen *et al*. (2004) analysed the growth of purebred Angus cattle and found that the cubic effect of age showed the best fit.

Wilson (1984) proposed formulae for the estimation of body weight in camels. The first formula utilizes the body measurements, viz. chest girth, abdominal girth, shoulder height and the second formula was based on the linear regression of the girth alone but proposed that the results are only reasonably acceptable. Khanna *et al.* (1990) utilized the step-wise multiple regression analysis using heart girth alone and observed that the prediction of 6 months, 2 years and 3 years body weight was satisfactory but that of 1 year was not in line with the other 3 body weights. Beniwal and Chaudhary (1983) compared linear function ($Y= a + bX$) and exponential functions ($Y= ae^{bx}$ and $Y=aX^b$) to explain the growth pattern in Bikaneri camels up to 30 months age of and the linear growth equation was observed as the best with R^2 value of 0.9412. The R^2 values for the linear and exponential functions in the present investigation were 0.661 and 0.45, respectively. Hence the cubic regression (R^2= 0.994) can be preferred over other functions to predict the growth of camels on the basis of age. The cubic regression equations (Table 2) may, therefore, be utilized for the prediction of body weight at any stage of age in the 2 sexes and the 4 genotypes of the dromedary.

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