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Growth Modeling and Genetic Analysis on Growth Traits of Sirohi Goat under Field Conditions

Research Article

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ABSTRACT

The data on 6772 growth records of Sirohi goats maintained at All India Coordinated Research Projecton Sirohi goat at Livestock Research Station, Vallabhnagar, Udaipur, India, and recorded between 2004 and 2016, were analysed to study the growth related traits and their genetic control. The overall least squares means of body weight at birth, W3M, W6M, W9M, W12M, were 2.34 ± 0.03, 12.44 ± 0.19, 16.31 ± 0.22, 20.08 ± 0.47 and 25.09 ± 0.40 kg, respectively while least-squares means for pre- and post-weaning average daily gains were 113.66 ± 2.15 and 46.17 ± 0.94 g/day, respectively. The various non-genetic factors exhibited variable effects on the growth traits at different phases of age. Cluster and period of birth had significant effect on all growth traits. Season of birth had significant effect except birth weight. Summer born kids heavier and higher body weight and pre- and post-weaning gains than winter and rainy season born kids. Males had a higher weight and higher daily gain than females at almost all stages of growth. Kids of primiparous dams had significantly lower birth weight as compared to multiparous dams' kids. Single born kids had a distinct advantage over those born in multiple births at all stages of growth. The regression on dam's weight at kidding were positive significant for all stages of growth traits. The heritability estimates of all body weights and weight gains at different stages of growth were moderate (0.16-0.28), except for post-weaning average daily gain, which had low heritability (0.07±0.01). The phenotypic and genetic correlations among the different growth traits were positive and high, except for phenotypic correlation between pre- and post-weaning gains which was negative. Four non-linear growth models, viz., Gompertz, Brody, Logistic and Von Bertalanffy were used to describe the growth pattern in Sirohi kids based on the growth parameters. The highest R^2 value and lowest mean absolute error (MAE), akaike's information criteria (AIC) and mean absolute percentage error (MAPE) values were observed in Brody model.

KEY WORDS growth traits, heritability, non-genetic factors, non-linear model, Sirohi goat.

INTRODUCTION

Goat is an important economic species of livestock in developing countries. India is endowed with 28 recognized goat breeds by National Bureau of Animal Genetic Resources, India. India stands on second position regarding goat population in the world with 135.07 million goats which is 26.40% of total livestock population of the nation. Rajasthan, one of the most important states of India in respect to goat husbandry, holds 21.66 million goats which is 16.03% share of the total goat population of India. Goat, a cow of poor man, provides milk and meat which are the important source of animal protein. In India, about 3% of total milk is produced by goats whereas contribution in meat is about 14.25%. Goat meat is released throughout the nation due to lack of any ritual taboo and good palatability. Sirohi goat is one of the best dual-purpose breed found predominantly in southern region of Rajasthan. Important traits for genetic improvement in kid breeding enterprises include the growth charactristics of the animals.

Growth rate in terms of body weight at market weight is one of the main determinants of profit from goat farming for pastoral communities and poor villagers. For betterment of meat production and to make the goat husbandry more profitable, higher body weight at market age is under demand. This can be achieved by genetic and non-genetic improvement in the growth traits. Growth traits of kids at different ages are influenced by many genetic and non-genetic factors with lifetime production and reproduction (Khadda *et al.* 2017).

An effective breeding plan can only be formulated after thorough knowledge has been obtained about the inheritance of important economic growth traits. Estimates of heritability and genetic and phenotypic correlations form the basis of such information. The non-linear models can be used to describe the growth curve characteristics in order to obtain biologically important growth parameters (Nimse *et al.* 2018). The growth curve is represented mathematically as a function of age and live weight, covering all or part of the animal's lifespan (Echverri *et al.* 2013). These growth curves show initially a self-acceleration stage (slope increase) followed by a deceleration stage (slope decline) (Brody, 1945). Growth curve models are of great importance for animal production, determine nutritional requirement and assessing the genetic potential of animals for growth. Information on growth rate in the form of body weight, average daily gain and parameters of growth curve on this breed of goat is scanty. The objective of this study was planned to evaluate the estimate of genetic and environmental parameters of different components traits related to growth and to determine the best non-linear growth curve models for the growth performance of Sirohi goat. Therefore, the important tool can be applied to develop a proper selection for an effective genetic improvement programme of Sirohi goat.

MATERIALS AND METHODS

Study area

The study area is located in southern part of Rajasthan, India and situated at 582m above mean sea level (24˚ 35" N and 73˚ 43" E) characterized by semi-arid climatic conditions with undulated topography having an average rainfall of 800 mm mainly during monsoon season from July to September. Similarly, the temperature ranges from 2.3 ˚C to 42.3 ˚C. Breeding bucks properly tagged were reared and maintained at LRS under All India Co-ordinated Research Project on goats (AICRP), Vallabhnagar, Udaipur during off breeding season and distributed amongst identified farmers during breeding seasons. The kids born out of such mating were tagged and their pedigree records were maintained at LRS, Vallabhnagar.

Feeding and management

Animals were allowed to graze freely during day time and during night confined to sheds. Sorghum straw, tree leaves, straw of different pulses and grasses were fed to goats under field conditions.

Green and dry fodder was fed to goats by some goat keepers as per availability under field conditions. Goats were vaccinated against enterotoxaemia and peste des petites ruminants by livestock assistant of project.

Ethical permission

Data were collected from the farmers' flock and animals for closely monitored and were provided managemental inputs as per the farmers. So the ethical permission was not mandatory in case of field data.

Data description

Data for the present study were collected from Sirohi farmers' flocks maintained under AICRP on Sirohi goat at Livestock Research Station, Vallabhnagar, Udaipur. Data on 6772 Sirohi kids of 144 sires were collected for birth, 3, 6, 9 and 12 months weights (kg) over a period of 12 years i.e. 2004 to 2016.

The environmental effects studied were cluster, period, season, parity, types of birth, sex and dam's body weight at kidding. The data were classified into seven clusters viz. Vallabhnagar and Salumber (Udaipur), Railmagra, Devgarh and Nathdwara (Rajsamand), Bhadsoda and Bojunda (Chittorgarh). The duration of kidding was divided into 4 periods each consisted of 3 years, viz. P_1 (2004-07), P_2 (2007-10), P_3 (2010-13) and P_4 (2013-16) and year was divided into 3 seasons viz. rainy (Jul–Oct), winter (Nov-Feb) and summer (Mar-Jun). Parities were classified as 1, 2, 3, 4, 5 and > 5, types of birth as single and multiple and sexes as male and female.

The average daily gains in body weights from birth until weaning (WADG) and from weaning until the age of 12 months (PADG) were estimated by using the following formula (Brody, 1964).

Avarage daily gain= $(W_2-W_1) / (T_2-T_1)$

Where:
W_2: final body weight (kg).
W_1: initial body weight (kg).
T_2: age of the animal at the end of period (days).
T_1: age of the animal at the beginning of period (days).

Statistical analysis

The data were analyzed using mixed model least-squares maximum likelihood programme of (Harvey, 1990).

Heritability and genetic correlation were estimated by paternal half-sib correlation method. The standard error of heritabilty was estimated by using the formula as given by (Swiger *et al.* 1964).

The genetic and phenotypic correlations among different growth traits were estimated from analysis of variance/covariance using half-sib data as suggested by (Becker, 1975).

Effect of sire was estimated using mixed model incorporating sire as random effect. Whereas, cluster, period and season of birth, type of kidding, parity and sex were estimated as fixed effect. Dam's weight at kidding was estimated by considering it as co-variable. Following statistical model was used to analyze the data.

$$Y_{ijklmnop} = \mu + A_i + B_j + C_k + D_l + E_m + F_n + G_o + b(DW_{ijklmnop} - \overline{DW}) + e_{ijklmnop}$$

Where:

$Y_{ijklmnop}$: performance record of the p^{th} progeny of i^{th} sire belonging to j^{th} cluster, k^{th} season of birth, l^{th} period of birth, m^{th} parity, n^{th} type of birth and o^{th} sex.

μ: population mean.

A_i: random effect of i^{th} sire.

B_j: fixed effect of j^{th} cluster (j=1, 2, 3, 4, 5, 7, 8).

C_k: fixed effect of k^{th} season of birth (k=1, 2, 3).

D_l: fixed effect of l^{th} period of birth (l=1, 2, 3, 4).

E_m: fixed effect of m^{th} parity (m=1, 2, 3, 4, 5 and > 5).

F_n: fixed effect of n^{th} type of birth (n=1, 2).

G_o: fixed effect of o^{th} sex (o=1, 2).

$e_{ijklmnop}$: residual random error associated with $Y_{ijklmnop}$ and assumed to be identically and independently distributed with mean zero and constant variance.

$b(DW_{ijklmnop} - \overline{DW})$: regression coefficient of the trait on dam's weight at kidding.

$DW_{ijklmnop}$: dam's weight at kidding (continuous variable).

$\overline{DW}$: athematic mean of dam's weight.

Duncan's multiple range test as modified by (Kramer, 1957) was used to make pair wise comparisons among the least-squares means.

Non-linear regression growth curve models

The relationship between average body weight and age in months is non-linear in nature, it is reasonable to explore the use of non-linear models to fit the average body weight. For drawing growth curves, early growth periods can be explained the linear model but after these periods linearity will be distorted. Four asymptotic non-linear functions models were considered for fitting the average body weight data.

The four non-linear growth models Brody (Brody, 1945; von Bertalanffy (Bertalanffy, 1957); Logistic (Nelder, 1961); Gompertz (Laird, 1965) were used for drawing growth curves.

Nonlinear regression models considered in this study to describe body weight growth by age in Sirohi kids are presented in Table 1.

The four non-linear growth models in Table 1 were fitted separately for males and females and parameters of model were estimated by Levenberg-Marquardt irritation methods (Batesand Watts, 1988) which minimize sum of squared errors. In this research Statistix 10 software was used for parameters prediction and goodness of fit test.

To examine model performance (quality of prediction), coefficient of determination (R^2) is used. However, (Kvalseth, 1985) has emphasized that, although R^2 is quite appropriate even for non-linear models, uncritical use of and sole reliance on R^2 statistics may fail to reveal important data characteristics and model inadequacies. Hence, in addition to R^2, mean absolute error (MAE), mean absolute percentage error (MAPE) and akaike's Information criteria (AIC) (Table 5) were used as the goodness of fit criterion to access the suitability of models fitted. Following Topal and Bolukbasi (2018), the mean absolute error (MAE) and mean absolute percentage error (MAPE) were calculated as below:

$$MAE = \sum_{i}^{n} \frac{\lfloor y_i - \hat{y}_i \rfloor}{n}$$

$$MPAE = {}^{1}/_{n} \sum_{i}^{n} \frac{\lfloor y_i - \hat{y}_i \rfloor}{y_i}$$

Akaike's information criteria (AIC) were calculated as using the equation Burnham and Anderson (2004).

AIC: n × ln(RSS) + 2p

AIC is a good static for comparison of models of different complexity because it adjust the residual sum of squares (RSS) for number of parameters in the model. A smaller numerical value of AIC indicates a better fit when comparing models.

RESULTS AND DISCUSSION

Basic statistics of body weights (kg) at different ages of Sirohi goats are presented in Table 2. The number of kids observed at the age of 12 months was 64% lower than the number of kids observed at birth.

Table 1 Non-linear regression model

Equation	Functional form[1]
Gompertz	$W_t = A \times \exp(-B \times e(-K \times t))$
Brody	$W_t = A \times (1-B \times e(-K \times t))$
Logistic	$W_t = A / (1+B \times e(-K \times t))$
von Bertalanffy	$W_t = A \times (1-B \times e(-K \times t))^3$

[1] The growth curve parameters used in the different functions can be interpreted as follows: W_t: observed live weight at age t; A: time to infinite predicted mature live weight; the parameter 'A' is average weight at maturity, that is asymptotic limit of the weight when age (t) approaches infinity; B: folding point of growth t = 0; the proportion of the asymptotic mature weight to be gained after birth; K: growth rate; the rate with which weight approaches A, the asymptote, large value of k indicate that the animal would mature early and e: natural logarithm base and t time at when weight was observed.

Table 2 Characteristics of data structure for body weights of Sirohi goat

Trait	BW	W3M	W6M	W9M	W12M
No. of kid records	6772	6054	4855	3588	2448
Male kid records (%)	49.70	49.82	47.54	42.22	31.29
Female kid records (%)	50.30	50.18	52.46	57.78	68.71
No. of sire with progeny records	144	137	131	128	111
Mean	2.52	13.54	17.51	20.99	25.01
Standard deviation	0.53	2.27	2.80	3.33	4.02
Coefficient variation (%)	21.03	16.76	15.99	15.86	16.07

BW: birth weight; W3M: weight at 3 month; W6M: weight at 6 month; W9M: weight at 9 month and W12M: weight at 12 months.

The reasons for this reduction were mortality, culling of unproductive animals and sale of animals through farmers. The highest coefficient of variation (CV) was observed for body weights at birth (21.03) and the lowest CV (15.86) was for body weight at 12 months of age. The birth weight with high CV indicates a good scope of improvement. This indicates that different growth traits can be either improved by selecting sires of higher genetic potential or by providing better environmental conditions. Numbers of records (N), least-squares means (LSM) with their standard errors (SE) of BW, W3M, W6M, W9M, W12M, WADG (BW-W3M) and PADG (W3M-W12M) for Sirohi goat in various fixed effects are presented in Table 3.

The overall least-squares means of BW, W3M, W6M, W9M, W12M, were 2.34 ± 0.03, 12.44 ± 0.19, 16.31 ± 0.22, 20.08 ± 0.47 and 25.09 ± 0.40 kg, respectively (Table 3) while least-squares means for WADG and PADG were 113.66 ± 2.15 and 46.17 ± 0.94 g/day, respectively (Table 3).

The means of body weight in present study were slightly lower than those reported by (Mehta *et al.* 1997; Gowane *et al.* 2011; Dudhe *et al.* 2015) in Sirohi goats, however means for WADG and PADG were higher than those reported by Mehta *et al.* (1997). Higher growth during pre-weaning period might be attributed to maternal effect in the form of milk suckled up to weaning. Whereas, lower growth rate during post weaning period might be due to transition of feeding practices from pre- to post-weaning periods and higher incidence of morbidity resulting in respiratory and intestinal disorder of kids. Similar findings were also reported by Mehta *et al.* (1997) and Gowane *et al.* (2011) in Sirohi goats, Singh *et al.* (2009) in Jamunapari goats, Gupta *et al.* (2016) in Mehsana goats and Khadda *et al.* (2017) in Pantja goat.

Effect of sire

The random effect of sire was significant (P<0.01) on body weight at all stages of growth and average daily gain for PADG and PADG (Table 3). The significant effect of sire indicated that heavier sires could be used effectively for further improvement of growth traits and average daily gain in farmers' flocks. The similar results were accordance with reports of (Dudhe *et al.* 2015) in Sirohi and Khadda *et al.* (2017) in Pantja goats.

Effect of periods of birth

Periods of birth had highly significant (P<0.01) effect on body weight and weight gain at all ages and stages (Table 3). Body weight and average daily gains under this study were higher in the period of 2010-2013 as compared to other periods.

The performance of growth traits of different stages of age showed variable performance over the periods, which might be attributed to fluctuation in environment conditions such as climate, management, morbidity and availability of feed fodder.

The similar finding were corroborated with reported by Singh *et al.* (2007) and Singh *et al.* (2009) in Jamunapari goats, Dudhe *et al.* (2015) in Sirohi goats and Gupta *et al.* (2016) in Mehsana goats.

Effect of season of birth

Season had highly significant effect on W3M, W9M, W12M, WADG and PADG except birth weight on which it was non-significant. However, significant effect (P<0.05) of season was observed on W6M (Table 3). Most of the does had kidding during winter season (48.58%) followed by rainy season (36.84%) and less frequency of kidding during summer season (14.57%).

Table 3 Least square means along with standard errors of different growth traits in Sirohi goat[1]

Effect	BW	W3M	W6M	W9M	W12M	WADG	PADG
Overall	2.34±0.03 (6772)	12.44±0.19 (6054)	16.31±0.22 (4855)	20.08±0.47 (3588)	25.09±0.40 (2448)	113.66±2.15 (6054)	46.17±0.94 (2448)
Sire	**	**	**	**	**	**	**
Cluster	**	**	**	**	**	**	**
Vallabhnagar	2.19±0.04^{b} (485)	11.68±0.25^{b} (400)	15.93±0.32^{c} (256)	19.34±0.59^{b} (109)	22.26±0.78^{a} (55)	108.20±2.73^{b} (400)	40.03^{b}±2.48 (55)
Railmagra	2.35±0.04^{c} (1011)	13.58±0.23^{f} (927)	17.27±0.28^{d} (826)	20.61±0.54^{c} (635)	26.21±0.58^{c} (373)	125.30±2.60^{e} (927)	45.04^{c}±1.73 (373)
Devgarh	2.42±0.03^{d} (3181)	13.29±0..22^{e} (3010)	17.17±0.26^{d} (2727)	20.73±0.52^{c} (2273)	24.64±0.54^{b} (1682)	122.06±2.45^{d} (3010)	40.71^{b}±1.58 (1682)
Nathdawara	2.44±0.05^{d} (295)	12.82±0.29^{d} (262)	16.11±0.36^{c} (213)	19.42±0.64^{b} (127)	22.64±0.75^{a} (65)	116.40±2.20^{c} (262)	36.96^{a}±2.36 (65)
Bhadsoda	2.57±0.04^{e} (1446)	15.03±0.24^{g} (1183)	20.61±0.30^{e} (639)	26.03±0.57^{d} (363)	32.21±0.64^{d} (242)	139.41±2.64^{f} (1183)	60.52^{e}±1.97 (242)
Bojunda	2.37±0.08^{c} (197)	8.64±0.42^{a} (183)	13.27±0.53^{a} (158)	15.23±0.87^{a} (72)	22.56±1.60^{a} (31)	69.31±4.58^{a} (183)	53.74^{d}±5.40 (31)
Salumber	2.05±0.07^{a} (157)	12.07±0.41^{c} (89)	13.83±0.56^{b} (36)	19.19±1.38^{b} (9)	-	114.96±4.50^{c} (89)	-
Period	**	**	**	**	**	**	**
2004-2007 (**P$_1$**)	2.26±0.04^{a} (1442)	12.20±0.23^{a} (1369)	15.53±0.28^{a} (1240)	17.94±0.52^{a} (965)	22.70±0.51^{a} (687)	112.31±2.54^{a} (1369)	39.87^{a}±1.44 (687)
2007-2010 (**P$_2$**)	2.27±0.03^{a} (1694)	12.21±0.21^{a} (1501)	15.97±0.25^{b} (1203)	19.61±0.49^{b} (980)	24.27±0.45^{b} (700)	112.29±2.33^{a} (1501)	44.38^{b}±1.18 (700)
2010-2013 (**P$_3$**)	2.40±0.03^{b} (1846)	12.97±0.21^{c} (1623)	16.78±0.25^{d} (1185)	21.74±0.49^{d} (912)	26.89±0.46^{c} (639)	118.38±2.35^{b} (1623)	50.47^{c}±1.23 (639)
2013-2016 (**P$_4$**)	2.43±0.04^{b} (1790)	12.39±0.23^{b} (1561)	16.26±0.27^{c} (1227)	21.03±0.52^{c} (731)	26.50±0.52^{c} (422)	111.68±2.52^{a} (1561)	49.94^{c}±1.46 (422)
Season	NS	**	*	**	**	**	**
Rainy (**S$_1$**)	2.35±0.03 (2495)	12.25±0.19^{a} (2279)	16.22±0.23^{a} (1816)	20.08±0.47^{b} (1343)	24.65±0.41^{a} (859)	111.38±2.17^{a} (2279)	45.16^{a}±0.99 (859)
Winter (**S$_2$**)	2.35±0.03 (3290)	12.48±0.19^{b} (2917)	16.22±0.23^{a} (2344)	19.86±0.47^{a} (1712)	24.73±0.41^{a} (1226)	114.06±2.18^{b} (2917)	45.16^{b}±0.98 (1226)
Summer (**S$_3$**)	2.32±0.03 (987)	12.59±0.20^{b} (858)	16.50±0.23^{b} (695)	20.29±0.47^{c} (533)	25.89±0.43^{b} (363)	115.55±2.24^{c} (858)	48.18^{c}±1.06 (363)
Parity	**	NS	*	NS	NS	NS	NS
1	2.29±0.03^{a} (1542)	12.39±0.20 (1393)	16.26±0.23^{b} (1194)	20.18±0.47 (922)	25.37±0.42 (652)	113.90±2.22 (1393)	47.04±1.02 (652)
2	2.34±0.03^{b} (1292)	12.43±0.20 (1158)	16.43±0.23^{b} (962)	20.18±0.47 (710)	25.24±0.42 (463)	113.57±2.21 (1158)	46.66±1.03 (463)
3	2.34±0.03^{b} (1136)	12.51±0.20 (1024)	16.34±0.23^{b} (816)	20.19±0.47 (601)	25.23±0.42 (416)	114.44±2.21 (1024)	46.66±1.04 (416)
4	2.34±0.03^{b} (961)	12.39±0.20 (846)	16.35±0.24^{b} (660)	20.11±0.48 (492)	24.90±0.43 (348)	113.03±2.23 (846)	45.65±1.06 (348)
5	2.35±0.03^{b} (1656)	12.36±0.20 (1456)	16.11±0.23^{a} (1054)	19.86±0.47 (749)	24.94±0.42 (498)	112.64±2.20 (1456)	45.73±1.03 (498)
6 and above	2.39±0.04^{c} (185)	12.59±0.24 (177)	16.39±0.28^{b} (169)	19.95±0.52 (114)	24.84±0.54 (71)	114.40±2.62 (177)	45.25±1.55 (71)
Type of Kidding	**	**	**	**	**	**	NS
Single	2.74±0.03 (4303)	13.11±0.19 (3906)	17.04±0.22 (3256)	20.77±0.47 (2451)	25.84±0.40 (1701)	114.75±2.16 (2148)	46.18±0.95 (1701)
Multiple	1.94±0.03 (2469)	11.77±0.20 (2148)	15.58±0.23 (1599)	19.38±0.47 (1137)	24.34±0.41 (747)	112.58±2.22 (3016)	46.16±1.00 (747)
Sex	**	**	**	**	**	**	**
Male	2.46±0.03 (3366)	12.97±0.19 (3016)	17.00±0.23 (2308)	20.90±0.47 (1515)	26.27±0.41 (766)	117.75±2.16 (3016)	48.87±0.99 (766)
Female	2.22±003 (3406)	11.91±0.19 (3038)	15.63±0.01 (2547)	19.25±0.47 (2073)	23.91±0.40 (1682)	109.57±2.18 (3038)	43.46±0.94 (1682)
Dam's weight regression	0.023±0.002**	0.065±0.011**	0.068±0.015**	0.086±0.021**	0.151±0.031*	0.32±0.127*	0.23±0.108*

[1] No. of observation in parenthesis.

BW: birth weight; W3M: weight at 3 month; W6M: weight at 6 month; W9M: weight at 9 month; W12M: weight at 12 months and PADG: post-weaning average daily gain.

* (P<0.05) and ** (P<0.01).

NS: non significant.

However, kids born in summer season had significantly higher growth traits as compared to rainy and winter born kids. This might be due to the better health and nutrition of their dam they got during summer seasons. After three month of age, maternal effect is reduced and growth of kids depends upon availability of adequate biomass in grazing area and congenial environment conditions. High parasitic infestation during rainy season made the kids vulnerable to various kinds of infections, which resulted in their lower growth. The differences may be further investigated in relation to marketing trend and consumer demaond of goat meat. Similar findings were also reported by Mehta *et al.* (1997) in Sirohi goat, Rai *et al.* (2004) in Marwari goat, Kumar *et al.* (2005) in Tellicherry goats, Yadav *et al.* (2008) in Kutchi goats, Singh *et al.* (2007) and Singh *et al.* (2009) in Jamunapari goat and Gupta *et al.* (2016) in Mehsana goats.

Effect of types of birth

Types of birth of kids had highly significant (P<0.01) effect on the growth from birth to 12 month of age and pre-weaning average daily gain (ADG) except post-weaning ADG (Table 3). Single born kids were 0.8 kg heavier than multiple kids at birth and this difference increased with age untill 6 month of age and 12 month of age. However, the difference in the rate of weight gain per day for single-born kids compared to multiple born kids was 8.10 g up to weaning and 5.41 g by 12 months of age, the later not being significant. The significant effect of the type of birth on the weaning age of the kids resulted in the ratio of the weights of kids from single to multiple births being 1.41 at birth, which lowered down to 1.06 at 12 months of age. This trends may be attributed to reduced nursing of the kids by their mothers, especially after weaning. However, kids born in multiple births grew faster than single born kids with the advancement of age. Similar finding were also reported by Mehta *et al.* (1997) and Dudhe *et al.* (2015) in Sirohi goat, Kutchi goat by Yadav *et al.* (2008) and Jamunapari goat by Singh *et al.* (2009).

Effect of sex of kid

Males were heavier (P<0.01) than females at birth and maintained their superiority for body weight over female contemporaries at later ages (Table 3). The average daily weight gains were also higher in males as compared to female kids. The difference in average daily gain between male and female kids decreased from 8.18 g to 5.41 g per day at 12 month of age. Higher values of all body weight traits at all stages of growth was observed for male kids compared to female kids. According to (Hafez, 1962), higher live weight of males is due to the anabolic effect of male hormones.

These hormone made male aggressive for suckling and feeding as compared to females. Results were in agreement with the reports of Singh *et al.* (2009) in Jamunapari, Mandal *et al.* (2010) in Jakhrana goats, Dudhe *et al.* (2015) in Sirohi and Gupta *et al.* (2016) in Mehasana goats.

Effect of cluster

Growth traits were significantly affected by the cluster (P<0.01) at all stages. Significantly higher mean body weight and pre- and post average daily gain was observed in Bhadsora cluster as compared to other clusters. The cluster-wise variation might be due to the difference in managemental practices followed by farmers, grazing resources and feed availability. In addition, variation in socio-economic status, flock size, supplementation level and housing practices might also be responsible for cluster wise variation in growth traits. Results were in agreement of those reported by Husain *et al.* (1996) in Black Bengal goats, Tyagi *et al.* (2013) in Surti goats, Dudhe *et al.* (2015) in Sirohi goat and Khadda *et al.* (2017) in Pantja goat.

Effect of parity on body weight

The differences in body weight and pre- and post-weaning daily gains were non-significant over the parity except body weight at birth and 6 months of age were significant (Table 3).

The maximum birth weight was in kids born to dams in parity 6 and above and minimum birth weight was observed in parity one. There may be relative competition for nutrient intake between still growing dams and developing fetus for the decrease in birth weight in kids born to younger dams. This may be influence of the age of the dam on her pre-natal effect on the birth weight of kids. Similar results were reported by (Singh *et al.* 2009) in Jamunapari goat and Dudhe *et al.* (2015) in Sirohi goat.

Dam's weight at kidding

The regression on dam's weight at kidding were positive and highly significant at all the body weights (Table 3). However, significant effect (P<0.05) were also observed during pre- and post-weaning daily gains. Results suggested that the heavy pregnant dams delivered heavier kids. Heavier kids at birth had better growth during subsequent stages also because of heavier dams provided better nourishment and more space for developing fetus. These results were in close agreement with the finding of Arora *et al.* (2011) in Sirohi goats and Singh *et al.* (2009) and Singh *et al.* (2013) in Jamunapari goats.

Genetic and phenotypic parameter estimates

The genetic parameters of growth traits are presented in Table 4.

Table 4 Estimate of heritability (on diagonal), genetic correlation (above diagonal) and phenotypic correlation (below diagonal) among growth traits at different ages in Sirohi goats

Traits	BW	W3M	W6M	W9M	W12M	WADG	PADG
BW	**0.22±0.030**	0.54±0.08	0.48±0.09	0.52±0.09	0.49±0.09	0.40±0.10	0.15±0.14
W3M	0.34±0.02	**0.28±0.034**	0.89±0.03	0.84±0.04	0.82±0.05	0.99±0.03	0.13±0.14
W6M	0.26±0.02	0.69±0.01	**0.20±0.029**	0.92±0.02	0.83±0.04	0.88±0.03	0.28±0.14
W9M	0.26±0.02	0.54±0.01	0.74±0.01	**0.20±0.029**	0.92±0.02	0.82±0.04	0.50±0.11
W12M	0.30±0.02	0.44±0.01	0.56±0.01	0.77±0.01	**0.16±0.026**	0.80±0.05	0.67±0.08
WADG	0.15±0.02	0.98±0.01	0.67±0.01	0.51±0.01	0.42±0.02	**0.26±0.03**	0.11±0.14
PADG	0.04±0.02	- 0.15±0.01	0.18±0.01	0.51±0.01	0.81±0.02	- 0.17±0.01	**0.07±0.01**

BW: birth weight; W3M: weight at 3 month; W6M: weight at 6 month; W9M: weight at 9 month; W12M: weight at 12 months; WADG: weaning average daily gain and PADG: post-weaning average daily gain.

Table 5 Estimated model parameters (±SE) and goodness of fit statistics for the non-linear models of body weights of male and female kids in Sirohi goat

Model[1]	A	B	K	R^2	MAE	AIC	MAPE	χ^2
Male								
Brody	30.98±5.28	0.90±0.047	0.42±0.163	98.6	0.928	4.37	0.08	0.33^{ns}
Gompertz	26.91±3.63	0.65±0.25	0.87±0.33	96.8	1.424	8.30	0.16	0.98^{ns}
Logistic	25.89±3.51	1.60±0.91	1.26±0.55	95.0	1.758	10.59	0.23	1.76^{ns}
von Bertalanffy	27.67±3.83	0.49±0.08	0.725±0.26	97.5	1.27	7.20	0.13	0.72^{ns}
Female								
Brody	27.25±3.60	0.89±0.04	0.46±0.15	98.8	0.766	2.36	0.07	0.24^{ns}
Gompertz	24.08±2.73	0.65±0.25	0.94±0.32	97.2	1.23	6.78	0.15	0.77^{ns}
Logistic	23.23±2.74	1.63±0.94	1.36±0.56	95.3	1.568	9.30	0.22	1.47^{ns}
von Bertalanffy	24.70±2.80	0.49±0.08	0.786±0.25	97.8	1.084	5.54	0.12	0.55^{ns}

R^2: coefficient of determination; MAE: mean absolute error; AIC: akaike's Information criteria; MAPE: mean absolute percent error and χ^2: chi-square goodness of fit value.

The heritability estimates for body weights were moderate ranged from 0.16 ± 0.026 for 12 months body weight to 0.28 ± 0.034 for 3 months weight. The moderate estimate of heritability indicated existence of additive genetic variance in their traits and scope of further improvement through effective selection and managemental practices. Variation in the estimates with the advancement of age could be attributed to variation in managemental practices which are associated with increasing of ages. The moderate heritability estimates of different body weights of kids observed in present study were in close agreement with those reported by Rai *et al*. (2004); Singh *et al*. (2009) and Singh *et al.* (2013). The heritability estimates for WADG and PADG were moderate and low, respectively and significantly different from zero indicating the further scope of improvement through selection.

Most of the phenotypic and genetic correlations of among different growth traits were positive and of medium to high magnitude showing no genetic antagonism between them. Genetic correlations between all body weight traits ranged from 0.48 ± 0.09 between BW and W12M to 0.92 ± 0.026 between W6M and W12M. This indicates that body weights are closely related and may be governed by same quantitative traits loci and hence improvement in any one trait may lead to the genetic improvement in other associated traits.

For average daily gain, it was observed that W3M with PADG and WADG with PADG had negative phenotypic correlations due to compensatory growth effect. Similar results were agreement with reported by Gowane *et al.* (2011) and Gupta *et al*. (2016). The result of the study indicated that selection weight and weight gain should be done on the basis of the post-weaning traits.

Parameters for growth curve

Estimation of growth parameters 'A', 'B' and 'K' were determined using all the four non-linear models for the body weight of male and females separately. The estimated non-linear growth model parameters 'A', 'B' and 'K' along with goodness of fit statistics, viz., R^2, MAE,MSE, AIC, MAPE and χ^2 values of Sirohi goats are presented in Table 5. Estimated parameter 'A' was highest for males as compared to females in all the four models, while 'B' and 'K' did not show any trends. The highest values of parameters 'A' for males and females were observed in Brody (30.98±5.28 and 27.25±3.60) and lowest values were observed in Logistic (25.89±3.51 and 23.23±2.74) growth models. Further, the estimated standard errors for parameter 'A' were found to be smaller for females as compared to males in all the four non-linear models. This may indicates that adult body weight higher as compared contemporary adults female body weight.

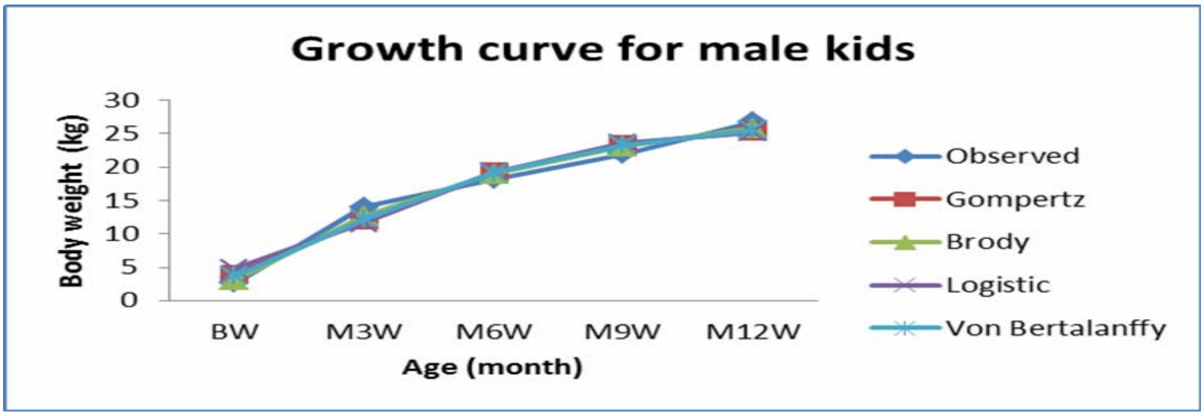

Figure 1 Growth curve for observed body weights along with non-linear models predicted weight for Sirohi male kids

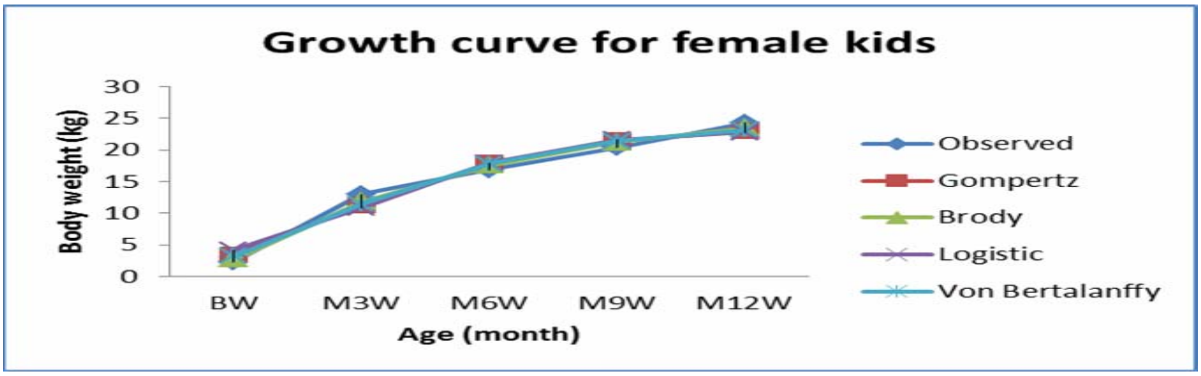

Figure 2 Growth curve for observed body weights along with non-linear models predicted weight for Sirohi female kids

The weight difference between birth and mature weight represents the proportion of weight gained after birth "B". The proportion of weight gained after birth "B" will amount to about 0.906 and 0.907 for male and female kids respectively, opposed to an estimate of 0.90, 0.65, 1.60 and 0.49 for male and 0.89, 0.65, 1.63 and 0.49 for female by Brody, Gompertz, Logistic and von Bertalanffy model. Estimate of 'B' was overestimates for Logistic model for both males and females (1.60±0.91 and 1.63±0.94) and lowest for von Bertalanffy model (0.49±0.08 and 0.49±0.08). In both sexes the Brody model gave similar estimates for the "B" parameter with actual proportion weight gained value than other models.

Parameter "K" estimates as 0.46, 0.94, 1.36 and 0.49 was observed higher in female as compared parameter "K" estimates as 0.42, 0.87, 1.26 and 0.73 for male Sirohi goat. Similarly, the estimate for 'K' was highest for Logistic model for males and females (1.26±0.55 and 1.36±0.56) and smallest for Brody model (0.42±0.163 and 0.46±0.15), respectively (Table 5). This may indicated that female have higher maturity rates.

Therefore, females acheived asymptotic weight earlier as compared male Sirohi goat.

Goodness of fit

In this study, all the non-linear models performed well with high R^2 values of over 95%. However, in females, Brody model was superior with highest R^2 (98.8%) and lowest MAE (0.766), MAPE (0.07) and AIC (2.36) values than the other models. For males, Brody model was superior with highest R^2 (98.6%) and lowest MAE (0.928), MAPE (0.08) and AIC (4.37) values respectively as compared to other models. Brody model was found to be the best model for describing the growth curve of Sirohi goat. Observed and predicted values for all the models for males and females are graphically shown in Figure 1 and Figure 2, respectively. Examination of the graph clearly shows smaller discrepancy between observed and predicted values supporting the findings. Similar results were reported by (Topal *et al.* 2004) in Awassi sheep, (Tater *et al.* 2009) in young hair goats, (Ganesan *et al.* 2015) in Madras red sheep, (Balan *et al.* 2017) in Mecheri sheep and Nimase *et al.* (2018) in

Madgyal sheep.

CONCLUSION

It is concluded from results of the present study that cluster, period, types of kidding and sex of kids were the major factors affecting on all stages of growth traits in Sirohi goats. These significant factors should be given due importance in general management and formulation of breeding strategies. The effect of birth month suggests that planning of kidding season would improve production efficiency. The moderate heritability indicated that selection for weight and average daily weight gain should be done on the basis of the post-weaning traits preferably on prior six month of age. High and positive genetic correlation of 6 month body weight with 9 and 12 months body weight indicates that males for breeding programme should be selected at prior 6 month of age. Brody growth model described average body weight growth curve remarkable well and it can be used for regulating feeding regimes and determination of manage

ment problems thus improvement in overall productivity.

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