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Comparison of sire evaluation methods for growth traits in Nellore Jodipi sheep by LS, BLUP and DFREML methods

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Abstract
Breeding values were estimated for body weights at birth, 3, 6, 9 and 12 months of age in Nellore Jodipi sheep maintained at Net Work Project on Sheep Improvement (NWPSI), Livestock Research Station, Palamaner of Chittoor district, Andhra Pradesh, India. Records on production traits of 4969 Nellore Jodipi lambs from1993 to 2016 (23 years) descended from 188 sires were included in the analysis. Analyses were carried out by least-squares (LS), best linear unbiased prediction (BLUP) and derivative free restricted maximum likelihood (DFREML) methods. BLUP method had the lower error variance (kg^2) for all the production traits as 0.18 for BW, 8.90 for 3M, 13.73 for 6M, 16.19 for 9M and 16.13 for 12M. Whereas, in LS and DFREML methods the error variances (kg^2) for these traits were 0.18, 0.18 for BW; 8.90, 9.15 for 3M; 13.74, 14.07 for 6M; 16.22, 16.51 for 9M; 16.19, 16.30 for 12M body weights. The coefficient of R^2 (%) values obtained for the traits were 22 (BW), 31 (3M), 34 (6M), 37 (9M) and 45 (12M) by LSM, followed by BLUP as 18 (BW), 27 (3M), 30 (6M), 31 (9M) and 37 (12M). For DFREML 9 (BW), 22 (3M), 22 (6M), 18 (9M) and 17 (12M).Spearman's rank correlation for DFREML with BLUP and LS estimates were highly significant ($P<0.01$). The rank correlations between BLUP and DFREML were greater than 0.9 for all the traits indicating that any of these two methods of sire evaluation could select the same set of sires with almost similar ranking for unbiased estimates of breeding values for production traits. The BLUP method seems to be the most efficient (lower error variance) and LSM as the most accurate (higher coefficient of determination) method for the evaluation of production traits in Nellore Jodipi sheep, but the accuracy of BLUP was much closer to LSM.

Keywords: Comparison, breeding value, body weights, LSM, BLUP, DFREML

1. Introduction

The economics of sheep production is greatly affected by growth rate as heavier lambs with higher growth rate fetch relatively more economic returns in lesser time as compared to weaker lambs (Narula *et al.*, 2009) [1]. The effectiveness of sire evaluation is the backbone of any breed improvement programme as the contribution of sire path is higher than the dam path for the overall genetic improvement of a trait due to a higher intensity of selection. Sire evaluation is one of the most important aspects of breed improvement programs which involves the estimation of breeding value and the success of the program depends on how early and accurately young rams can be evaluated for breeding value to a desired trait. Hence, in the present investigation, an attempt was made to estimate the breeding values of Nellore Jodipi rams for growth traits using Least squares (LS), Best Linear Unbiased Prediction (BLUP) and Derivative Free Restricted Maximum Likelihood (DFREML) methods and in turn to identify the most effective method of sire evaluation.

2. Materials and Methods

Data recorded on production traits of 4969 Nellore Jodipi lambs from1993 to 2016 (23 years) descended from 188 sires from Net Work Project on Sheep Improvement (NWPSI), Livestock Research Station, Palamaner of Chittoor district, Andhra Pradesh, were included in the analysis. Sires having three or more progeny were alone included in the analyses. Breeding values of sires for body weights at birth (BW), 3 months (3M), 6 months (6M), 9 months (9M) and 12 months (12M) of age were estimated by least squares, BLUP and DFREML methods.
The animals in the farm were grouped according to age, sex and physiological status such as pregnant, lactating or dry ewes and housed in well-ventilated sheep sheds at recommended

stocking densities. Animals are housed on mud flooring, open pen and run system with asbestos roofing. Rams and ewes were housed separately. New born lambs were housed with their mothers up to 90 days after lambing and thereafter weaned and housed separately in young pens. Weight of new born lamb was taken within 10 hours of birth, remaining weights at 3, 6, 9, and 12 months of age were recorded precisely on exact dates. Ewe and ram lambs were separated at about six months of age.

Semi-intensive system of rearing is followed. Animals are allowed for grazing in the farm grazing land for about eight hours a day. In addition to grazing, the animals were provided with 200-250 gm of concentrate mixture. Sires used for breeding were retained in the flock for at least 2 years; males were selected based on their 6 months weight. Selection was not practiced for ewes. Females were bred either at an age of 15 months or after attaining 25 kg body weight. Lambing in the flock was seasonal mainly observed in two seasons i.e., main season (November-March) and off season (June-October). Animals were vaccinated against PPR, enterotoxaemia, FMD etc.

Data on production traits was classified at various ages according to period of birth, season of birth, parity of the dam and sex of the lamb. The period of birth from 1993 to 2016 was divided into 6 periods, each comprising 4 years. Each year of lambing was also divided into 2 seasons, i.e. main season (November-March) and off season (June-October). Parity into six classes and sex into two (Male and Female). The following statistical procedures were followed for estimation of breeding values by least squares, BLUP and DFREML methods.

2.1 Least squares method (LSM): Using LSMLW and MIXMDL (Harvey, 1990) programme, the breeding values of sires for production traits were estimated by least squares method by using the following mathematical model.

$$Y_{ijklmp} = \mu + S_i + P_j + N_k + X_l + T_m + e_{ijklmp}$$

Where,

Y_{ijklmp} = Observation on the trait of the p^{th} animal belonging to i^{th} sire, j^{th} period of birth, k^{th} season of birth, l^{th} sex of lamb, m^{th} parity of it's dam at lambing.

S_i = Effect of i^{th} sire

P_j = Effect of to j^{th} period of birth,

N_k = Effect of k^{th} season of birth

X_l = Effect of l^{th} sex of lamb

T_m = Parity of it's dam at lambing,

e_{ijklmp} = Random error associated with each observation (Y), NID $(0, \sigma^2_e)$

2.2 Best Linear Unbiased Prediction (BLUP)

Univariate sire model by using the LSMLMW and MIXMDL package of Harvey (1990) [2] was utilized to estimate the breeding values of sire for each production trait by BLUP (Henderson, 1973) [3] method as per the following general mixed model.

$$Y = Xb + Zu + e$$

Where,

Y = Vector of observations (No. of records x 1) with mean Xb and variance V

X = Known design matrix relating fixed effects to Y (No. of records x No. of levels of fixed effect)

'b' = Vector of unknown fixed effects (BLUE) (No. of levels of fixed effect x 1)

Z = Known design matrix relating animals to Y (No. of records x No of animals)

'u' = Vector of unknown breeding values (BLUP of EBV) (No. of animals x 1)

'e' = Vector of unknown random residual effects (No. of records x 1)

$V = ZGZ' + R$

$G = A\sigma^2_a$

$R = I\sigma^2_e$

Where,

A = Numerator relationship matrix of order (No of animals x No of animals)

I = Identity matrix of order (No of observations x No of observations)

σ^2_a and σ^2_e are the estimate of additive and residual variance, respectively, and were obtained from the best model determined for each trait.

The BLUE and BLUP values were obtained as:

$E(b) = (X'V^{-1}X)^{-1}X'V^{-1}Y$

$E(u) = GV^{-1}(Y-Xb)\ A\sigma^2_a (A\sigma^2_a + I\sigma^2_e)^{-1} (Y-Xb)$

The BLUP equations (Henderson's mixed model equation) were represented as:

$$\begin{pmatrix} X'X & X'Z \\ X'Z & Z'Z+A^{-1}\lambda \end{pmatrix} \begin{pmatrix} b \\ u \end{pmatrix} = \begin{pmatrix} X'Y \\ Z'Y \end{pmatrix}$$

Where,

$\lambda = \sigma^2_e / \sigma^2_a$

The BLUE and BLUP estimates were arrived by solving these equations as

$$\begin{pmatrix} b \\ u \end{pmatrix} = \begin{pmatrix} X'X & X'Z \\ X'Z & Z'Z+A^{-1}\lambda \end{pmatrix}^{-1} . \begin{pmatrix} X'Y \\ Z'Y \end{pmatrix}$$

2.3 Derivative Free Restricted Maximum Likelihood (DFREML)

DFREML computer programme under univariate model (Meyer, 1998) [4], was utilized to estimate the breeding values of sires for each production trait by following the general mixed model:

$$Y = Xb + Zu + e$$

Where Y, X, b, Z, u and e were similar to the above model.

2.4 Comparison of different sire evaluation methods:

Efficiency, accuracy and stability of LSM, BLUP and DFREML methods were compared by using different judging criteria like within sire variance (error variance), Relative efficiency (RE), coefficients of determination and coefficient of variation of those methods.

a. Error variance

The effectiveness (Efficiency) of Least squares, BLUP and REML methods was judged by (within sire variance) error variance. The method giving the lowest error variance had higher efficiency and was most appropriate. The efficiency was measured by the following equation.

$$\text{Efficiency} = \frac{1}{\text{Error Variance}}$$

b. Coefficients of determination (R^2-Value)

The coefficients of determination (R^2) values of three methods (LSM, BLUP & DFREML) were estimated for judging the accuracy of sire evaluation method. The model, which showed the highest R^2 value, was considered to be the most accurate method (Biostatistics for Animal Science, Kaps and Lamberson, 2004) [5]. The formula used to estimate the coefficient of determination value was

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}}$$

Where, SS_{res} = Residual sum of squares
SS_{tot} = Total sum of squares

c. Coefficient of Variation (CV%)

The estimates of the coefficient of variation (CV%) were used as criterion to compare the stability of different sire evaluation methods for body weight traits. The formula used for calculation of coefficient of variation was given below.

$$CV\,(\%) = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100$$

d. Spearman's rank correlation

The Spearman's rank correlation between breeding values of sires estimated by three methods (LSM, BLUP and DFREML) was used to judge the effectiveness of these methods. Higher rank correlation among the sires from different sire evaluation methods shows higher degree of similarity of ranking from different methods. The rank correlation was estimated as per Steel and Torrie (1980) [6].

$$r_s = 1 - \frac{6\sum d^2}{n\left(n^2 - 1\right)}$$

Where, r_s=Rank correlation coefficient
n=number of sires under evaluation
d=difference of rank between paired items under two methods
The significance of rank correlation was tested by t-test as given below

$$t = r\sqrt{\frac{n-2}{1-r_s^2}}$$

It was compared with t- distribution table value at (n-2) degrees of freedom.

3. Results and Discussion

Breeding values for body weight traits of sires were expressed as deviations from the population mean on the basis of the breeding value of their progeny by three different sire evaluation methods *viz.*, LS, BLUP and DFREML (Table 1). The estimated overall average breeding values of sires for BW, 3M, 6M, 9M and 12 M were found to be 3.09, 14.36, 19.04, 22.78, 24.73 kg by LSM; 2.96, 13.20, 18.12, 21.59 and 24.62 kg by BLUP method; 2.96,13.19, 18.11, 21.60 and 24.63 kg by DFREML methods.

The Estimated Breeding Values (EBV's) by LSM, BLUP and DFREML methods for BW ranged from 2.34 to 3.80, 2.69 to 3.31 and 2.72 to 3.28 kg, respectively. The top ranking sires had 22.98%, 11.82% and 10.81% higher genetic superiority over the average breeding value, whereas the bottom ranking sires had 24.7%, 9.12% and 8.11% inferiority (Breeding Value) than the average BV in LS, BLUP and DFREML methods, respectively. Out of 188 sires, 89, 100 and 99 sires had BV above the average, while 99, 88 and 89 sires had breeding value below the average in LS, BLUP and DFREML methods, respectively. The percentage of sires above the population mean were 47.34, 53.19 and 52.66 and below the population mean were 52.66, 46.81 and 47.34%, respectively for the above methods.

The average Breeding Values for body weights at 3M of age varied from 5.79 to 21.92 (LSM), 9.55 to 16.09 (BLUP) and 9.51 to 16.09 kg (DFREML). The top ranking sires had 52.65%, 21.89% and 21.99% higher genetic superiority over the average breeding value, whereas the bottom ranking sires had 59.68%, 27.65% and 27.90% lower BV (Breeding Value) than the average BV in LS, BLUP and DFREML methods, respectively. The percentage (%) of sires above the average were 50.00, 53.23 and 53.23 and below the population mean were 50.00, 46.77 and 46.77, respectively for the above methods (Table 1).

At 6M of age the Estimated Breeding Values (EBV's) for body weights by LS, BLUP and DFREML methods ranged from 8.81 to 27.00, 13.80 to 22.17 and 13.74 to 22.18 kg, respectively. The top most sires had 41.81% (LSM), 22.35% (BLUP) and 22.47% (DFREML) higher genetic superiority over the overall average.

Minimum to maximum Estimated Breeding Values (EBV's) by LSM, BLUP and DFREML methods for 9M body weight ranged from 12.72 to 32.98, 18.04 to 25.86 and 18.11 to 25.80 kg respectively. The top most sires had 44.78%, 25.86% and 25.80% higher genetic superiority over the average breeding value, whereas the bottom ranking sires had 44.16%, 16.44% and 16.16% lower BV (Breeding Value) than the average BV in LSM, BLUP and DFREML methods, respectively (Table 1). Out of 177 sires, the proportion of sires as reflected by simple numbers with BV's above the population mean were 83, 82 and 83 and below the population mean were 94, 95 and 94 respectively for LSM, BLUP and DFREML methods. The percentage of sires above the population mean were 46.89, 46.33 and 46.89% and below the population mean were 53.11, 53.67 and 53.11%, respectively for the above methods.

Table 1: Average breeding value estimates for production traits using different sire evaluation methods in Nellore Jodipi sheep

Traits	Sire evaluation method	Total no. of sires	Total no. of records	Average BV	Minimum BV (% below Avg BV)	Maximum BV (% above Avg BV)	Number of sires above the Avg BV (% of sires)	Number of sires below the Avg BV (% of sires)
	LS	188	4969	3.09	2.34 (24.7)	3.80 (22.98)	89 (47.34)	99 (52.66)
BW	BLUP	188	4969	2.96	2.69 (9.12)	3.31 (11.82)	100 (53.19)	88 (46.81)
	DFREML	188	4969	2.96	2.72 (8.11)	3.28 (10.81)	99 (52.66)	89 (47.34)
	LS	186	4490	14.36	5.79 (59.68)	21.92 (52.65)	93 (50.00)	93 (50.00)
3M	BLUP	186	4490	13.20	9.55 (27.65)	16.09 (21.89)	99 (53.23)	87 (46.77)
	DFREML	186	4490	13.19	9.51 (27.90)	16.09 (21.99)	99 (53.23)	87 (46.77)
	LS	185	4014	19.04	8.81 (53.73)	27.00 (41.81)	96 (51.89)	89 (48.11)
6M	BLUP	185	4014	18.12	13.80 (23.84)	22.17 (22.35)	90 (48.65)	95 (51.35)
	DFREML	185	4014	18.11	13.74 (24.13)	22.18 (22.47)	90 (48.65)	95 (51.35)
	LS	177	3036	22.78	12.72 (44.16)	32.98 (44.78)	83 (46.89)	94 (53.11)
9M	BLUP	177	3036	21.59	18.04 (16.44)	25.86 (19.78)	82 (46.33)	95 (53.67)
	DFREML	177	3036	21.60	18.11 (16.16)	25.80 (19.44)	83 (46.89)	94 (53.11)
	LS	171	2288	24.73	16.98 (31.34)	31.18 (26.08)	85 (49.71)	86 (50.29)
12M	BLUP	171	2288	24.62	20.21 (17.91)	28.50 (15.76)	86 (50.29)	85 (49.71)
	DFREML	171	2288	24.63	20.25 (17.78)	28.48 (15.63)	87 (50.88)	84 (49.12)

Similarly, the minimum to maximum Estimated Breeding Values (EBV's) of LSM, BLUP and DFREML methods for 12M body weight varied from 16.98 to 31.18, 20.21 to 28.50 and 20.25 to 28.48 kg, respectively. The top most sires had 26.08%, 15.76% and 15.63% higher genetic superiority over the average, whereas the bottom ranking sires had 31.34%, 17.91% and 17.78% lower BV (Breeding Value) than the average BV in LSM, BLUP and DFREML methods, respectively. Out of 171 sires, 85, 86 and 87 sires were superior and 86, 85 and 84 were inferior to the population mean, by LSM, BLUP and DFREML methods, respectively. The percentage of sires above the population mean were 49.71, 50.29 and 50.88% and below the population mean were 50.29, 49.71 and 49.12%, respectively for the above methods.

Efficiency, accuracy and stability of LSM, BLUP and DFREML methods were compared by using error sum of squares, relative efficiency (RE), coefficient of determination (CD), coefficient of variation (CV) and Spearman's rank correlation and details were presented in Tables 2 and 3.

3.1 Error sum of squares and Relative efficiency

The perusal of Table 2 revealed that BLUP method had the lower error variance (kg^2) for all the production traits as 0.18 for BW, 8.90 for 3M, 13.73 for 6M, 16.19 for 9M and 16.13 for 12M. Whereas, in LS and DFREML methods the error variances (kg^2) for these traits were 0.18, 0.18 for BW; 8.90, 9.15 for 3M; 13.74, 14.07 for 6M; 16.22, 16.51 for 9M; 16.19, 16.30 for 12M body weights. Hence, BLUP method was adjudged to be the most efficient method followed by LS and DFREML methods. Similar to the present findings Dubey *et al.* (2006) [7] in Sahiwal and its crosses; Bajeetha and Singh (2006) [8] in crossbred cattle also reported BLUP as the best procedure in comparison to other procedures of sire evaluation. In contrast to the present findings, Jeichitra *et al.* (2015) [9] in Mecheri sheep; Singh *et al.* (2016) [10] in Marwari sheep reported that DFREML as the most efficient method than other methods of sire evaluation for different growth traits.

The Relative efficiency of LSM over BLUP was same for BW (100%), whereas 99.9%, 99.9%, 99.8% and 99.6% for 3M, 6M, 9M and 12 M body weights, respectively. The relative efficiency of DFREML over BLUP was 98.8%, 97.2%, 97.5%, 98.1% and 98.9% for BW, 3M, 6M, 9M and 12 M body weights respectively. These results depicted that all the three methods have estimated breeding value with fairly high accuracy as relative efficiencies of LS and DFREML with respect to BLUP for all the body weight traits was higher than 90%.

3.2 Coefficient of determination (R^2%)

Accuracy of fitting the model was judged by the **c**oefficient of determination (R^2). The higher the R^2 value, higher was the accuracy of fitting the model. Highest R^2 (%) values obtained for the traits were 22 (BW), 31 (3M), 34 (6M), 37 (9M) and 45 (12M) by LSM, followed by BLUP as 18 (BW), 27 (3M), 30 (6M), 31 (9M) and 37 (12M). For DFREML 9 (BW), 22 (3M), 22 (6M), 18 (9M) and 17 (12M), which indicated that, LSM was best fitted model over the other two methods of sire evaluation, but the accuracy of BLUP was much closer to LSM. These results are comparable with the findings of Gandhi and Gurnani (1991) [11] in Sahiwal cattle. Whereas, Singh *et al.* (2016) [10] studied first lactation traits in Sahiwal cattle using Simple daughter's average, LSM and BLUP methods, and reported that LSM was found to be fittest over BLUP method, with a close accuracy between BLUP and LSM, which coincided with the present findings in Nellore Jodipi sheep. While Jeichitra *et al.* (2015) [9] in Mecheri sheep concluded that DFREML as the most accurate method of sire evaluation followed by LSM and BLUP which is dissimilar to the present study.

3.3 Coefficient of variation (CV%)

Estimates of coefficient of variation were used as criterion to compare the stability of sire evaluation methods. In general coefficient of variation increases with the advancement of age in case of growth traits upto weaning weight and thereafter it declines. In the present study similar trend was found for BLUP and DFREML methods.

Table 2: Effectiveness of different sire evaluation methods for production traits in Nellore Jodipi sheep

Method	Error variance (kg^2)	Relative efficiency	Coefficient of determination (R^2%)	Coefficient of variation (C.V%)
Birth weight				
LS	0.18	100	22	5.82
BLUP	0.18	100	18	14.70
Dfreml	0.18	98.8	09	15.80
3 months body weight				
LS	8.90	99.9	31	9.95
blup	8.90	100	27	23.43
Dfreml	9.15	97.2	22	26.67
6 months body weight				
LS	13.74	99.9	34	9.87
Blup	13.73	100	30	21.53
Dfreml	14.07	97.5	22	24.60
9 months body weight				
LS	16.22	99.8	37	11.41
Blup	16.19	100	31	20.02
Dfreml	16.51	98.1	18	22.84
12 months body weight				
LS	16.19	99.6	45	34.68
Blup	16.13	100	37	18.38
Dfreml	16.30	98.9	17	21.17

Table 3: Spearman's rank correlations for production traits among different sire evaluation methods in Nellore Jodipi sheep

Spearman's rank correlation	Estimate
Birth weight	
LSM - BLUP	0.651**
LSM - DFREML	0.636**
BLUP - DFREML	0.999**
3 months body weight	
LSM - BLUP	0.631**
LSM - DFREML	0.629**
BLUP - DFREML	0.997**
6 months body weight	
LSM - BLUP	0.657**
LSM - DFREML	0.674**
BLUP - DFREML	0.982**
9 months body weight	
LSM - BLUP	0.511**
LSM - DFREML	0.487**
BLUP - DFREML	0.962**
12 months body weight	
LSM - BLUP	0.836**
LSM - DFREML	0.881**
BLUP - DFREML	0.929**

** Highly significant (p<0.01) (2 tailed t- test)

3.4 Spearman's rank correlations
The rank correlations among breeding values of sires estimated from different methods of sire evaluation were all high, and all the values were highly significant (P<0.01). The values ranged from 0.487 (LSM with DFREML for 9M) to 0.999 (BLUP with DFREML for BW). The rank correlations between BLUP and DFREML were greater than 0.9 for all the traits indicating that any of these two methods of sire evaluation could select the same set of sires with almost similar ranking for unbiased estimates of breeding values for production traits (Table 3). Results of present work are similar to findings of Jeichitra *et al.* (2015) [9] in Mecheri sheep, Singh *et al.* (2016) [10] in Marwari sheep.

4. Conclusions
Comparison of LSM, BLUP and DFREML methods of sire evaluation revealed that BLUP as the most efficient method due to its lowest error variance and LSM, due to its highest coefficient of determination, was the most accurate method for BW, 3M, 6M, 9M and 12 M body weights in Nellore Jodipi sheep. The rank correlation coefficients amongst breeding values of sires by different methods of sire evaluation revealed a high degree of agreement in the ranking of sires. Thus the above said best methods could be considered before going to estimate the breeding values of production traits in Nellore Jodipi sheep.

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