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Phenotypic trend, breeding value and heritability of biometric traits in Marwari horses

SHARAT CHANDRA MEHTA[1]✉, THIRUMALA RAO TALLURI[1], RAMAVATAR LEGHA[1], YASH PAL[1] and BHUPENDRA NATH TRIPATHI[2]

ICAR-National Research Centre on Equines, Equine Production Campus, Bikaner, Rajasthan 334 001 India

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ABSTRACT

Analysis of phenotypic trend and estimation of inbreeding coefficient, breeding value and heritability of biometric traits was carried out for a total of 226 Marwari horses. The pedigree construct divided the entire population of 226 horses into 6 tiers spanning over a period of 30 years. The inbreeding coefficient of the herd was estimated to be 0.0017. The average height at withers, body length, heart girth and body weight of Marwari horses was 150.15±0.04 cm, 151.44±0.06 cm; 170.02±0.19 cm and 371.34±0.52 kg, respectively with non-significant effect of sex, tier and interaction of sex and tier. The Best Linear Unbiased Prediction (BLUP) estimate of breeding value for the height at withers (150.45 cm), body length (151.97 cm), heart girth (169.73 cm) and body weight (366.3 kg) for Marwari horses was –0.059 cm, –0.079 cm, 0.096 cm and 3.526 kg, respectively. The effect of sex and interaction of sex and tiers was non-significant but that of tier on the estimated breeding value for body weight was significant indicating that body weight received favour in breeding programme. The heritability of height at withers, body length, heart girth and body weight has been estimated to be 0.396±0.586, 0.370±0.777, 0.507±1.95 and 0.597±0.612, respectively. Negligible inbreeding and constant phenotype over decades indicated that the Marwari herd has been bred to maintain enough genetic variation and hence it can be the most reliable source of the stallions and mares for propagation and conservation of this legendry breed of horse which is getting diluted and declining at a faster rate.

Keywords: Biometry, Breeding value, Heritability, Inbreeding, Marwari horse, Pedigree

Marwari (Malani) breed of horse is the most popular and fascinating breed of horses in India. This breed is known for its endurance potential (Behl *et al.* 2007, Gupta *et al.* 2012). However, the population of Marwari horses in the country has been estimated to be 42,175 heads (Breed Survey 2013) and there had been 48.58% decline in the population of horses in the country during the quinquennial census period of 2012 to 2019 (Livestock Census 2019) indicating that the current population of Marwari horses would be around 25,000 heads. The Marwari horses are considered to have developed by breeding of Indian ponies having Mongolian inheritance with Arabian horses from 12th century onwards (Kaura 1961, Edwards 1994, Singh and Yadav 2004, Behl *et al*. 2007, Doniger 2009, Gupta *et al*. 2012). Based on historical references, it is also believed that the Marwari horses have been developed by breeding Kathiawari horses with the Arab, Persian, Turkestan, Sindhi / Baluchi and other similar breeds (Gadhvi 2017). Jun *et al*. (2014) confirmed strong Arabian and Mongolian inheritance in Marwari breed while doing whole genome sequencing and analysis of its genetic origin. It has also been apprehended that due to indiscriminate breeding, the breed characteristics are getting diluted and at present only a few thousand true Marwari horses are in existence (Singhvi 2001, Yadav *et al.* 2001, Mehta 2020). The reports presenting averages of biometric traits of Marwari horses belonging to the breeding tract are available (Singh *et al.* 2002, Gupta *et al.* 2012) but further analysis in terms of pedigree construction, inbreeding, breeding value, phenotypic trend over generations, selection and estimation of genetic parameters is absolutely lacking. Therefore, this study was planned to estimate the level of inbreeding, envisage the phenotypic gain over the years, estimate the breeding value of the available individuals and to estimate the heritability of the biometric traits, viz. height at withers (WH), body length (BL), heart girth (HG) and body weight (BWT) in Marwari horses.

MATERIALS AND METHODS

The Marwari horses maintained at ICAR-National Research Centre on Equines, Equine Production Campus, Bikaner, India were utilized for the purpose. These horses were maintained under intensive system of management with feed and water *ad lib*. Adult animals above 4 years of

Present address: [1]ICAR-National Research Centre on Equines, Equine Production Campus, Bikaner, Rajasthan. [2]Division of Animal Science, Krishi Bhavan, New Delhi. ✉Corresponding author email: scmehta64@gmail.com

age were measured. The body measurements, viz. height at withers (HW), body length (BL) and heart girth (HG), were taken as per standard procedure. Recording of live body weight was done in the morning. The biometric records since the year 1989 till 2020 were analysed.

Estimation of inbreeding coefficients, breeding values and pedigree analysis: The Pedigree Viewer Version 6.5b (Kinghorn and Kinghorn 2015) was used to draw the pedigree, find out the number of tiers (generations), calculate the inbreeding co-efficient of individuals as well as by tiers (generations). The BLUP (Best Linear Unbiased Prediction) estimate of the breeding value of the individuals was also calculated using the software taking sex as the fixed factor. Sequential Identification numbers were generated and the breeding values were saved against them for further analysis.

Estimation of heritability: Mixed model least-squares and maximum likelihood computer program PC-2 by Harvey (1990) was utilized for estimating the heritability of height at withers, body length, heart girth and body weight. Model 2 of the programme was used for the purpose taking the effect due to sire as random and those due to sex and period as fixed.

$$Y_{ijkl} = \mu + s_i + c_j + p_k + e_{ijkl}$$

where Y_{ijkl}, observation on i^{th} progeny of j^{th} sex in k^{th} year; μ, overall mean; s_i, random effect of i^{th} sire (i=1,2…n); c_j, fixed effect of the j^{th} sex (j = 1, 2); p_k, fixed effect of k^{th} year of birth (k =1, 2,….,n), and e_{ijkl}, random error which is normally and independently distributed with mean 0 and variance σ^2.

Statistical analysis: The height at withers, body length, heart girth and body weight data along with the estimated breeding values of the individuals for height at withers, body length, heart girth and body weight data were analysed against the tiers (generations) created by Pedigree Viewer software following sequential identification numbers. SPSS version 26 (IBM Corp. Released 2019) was used for statistical analysis including the analysis of variance and studying the effect of sex, tier (generation) and interaction thereof for each trait and their estimated breeding values. The statistical model used is represented below.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon$$

where Y, dependent variable; β_0, intercept (constant); β_1 and β_2, regression coefficient of Y on independent variable X_1 and X_2, respectively; ε, error term.

RESULTS AND DISCUSSION

Pedigree construction and inbreeding coefficient: A total of 195 records of Marwari horses, involving 226 individuals were analysed for their ancestral relationship and calculation of inbreeding co-efficient over generations using the Pedigree Viewer programme. The programme grouped the entire herd into 6 tiers corresponding to 6 generations, each spanning over a period of about 5 years. The maximum size of paternal family was 15 and that of maternal family was 8. The inbreeding coefficient was 0 for the first 4 tiers and little above 0 in the 5^{th} (0.0072) and 6^{th} (0.0078) tier. The results indicate that there had been negligible inbreeding over generations in the Marwari herd under study. This appropriately mean that the genetic variability and fitness in terms of health, vigour and fertility has been maintained to the greatest extent in the herd (Falconer 1981, Lacy 1997).

Body parameters: The average height at withers, body length, heart girth and body weight of stallions, mares and pooled over sexes was 150.62±0.13, 149.96±0.05, 150.15±0.04 cm; 152.50±0.24, 151.13±0.08, 151.44±0.06 cm; 169.33±0.88, 170.26±0.25, 170.02±0.19 cm and 362.03±1.57, 375.51±0.77, 371.34±0.52 kg, respectively with non-significant (P>0.05) effect of sex. The first, second, third, fourth and fifth tier encompassing the period from the year 1989 to 2020 had average height at withers 151.10±0.35, 149.38±0.16, 150.86±0.23, 149.81±0.10, 150.39±0.14 cm; body length 151.29±0.71, 150.86±0.27, 153.13±0.30, 151.33±0.18, 150.79±0.27 cm; heart girth 155.00±3.54, 166.56±1.03, 173.38±0.69, 170.63±0.75, 170.93±0.59 cm, and body weight 364.73±5.31, 357.92±1.58, 371.85±2.99, 374.11±1.65, 393.29±4.01 kg respectively. The tier means and the interaction of sex and tier on the biometric traits of the Marwari horses differed non-significantly (P>0.05). The analysis of variance and tier-wise means of biometric traits in the two sexes have been presented in Table 1.

In present investigation, the average height at withers was 150.15±0.04 cm, body length was 151.44±0.06 cm, heart girth was 170.02±0.19 cm and body weight was 371.34±0.52 kg for Marwari horses maintained at the Centre. The stallions measured slightly better for height at withers and body length and mares for heart girth and body weight as compared to the other sex. However, the effect of sex on the WH, BL, HG and BWT of stallions and mares was non-significant (P>0.05) indicating that no preferential breeding with respect to the sex of the animal has been practiced. The different tiers in males and females also did not differ significantly (P>0.05) showing that the breeding strategy over tiers (generations) did not had any preference for the traits under consideration. The interaction of sex with tier was also non-significant (P>0.05) indicating that non-preferential breeding with respect to different sexes in different tiers took place. Gharahveysi *et al*. (2008) worked out the statistical indicators of Iranian Arab horse for conformation traits and presented 149.17±0.33 cm withers height (WH), 148.54±0.46 cm body length (BL) and 169.45±0.50 cm heart girth circumference (HGC). Further, the United States Equestrian Federation (2008) described the height of Arabian horse as standing between 14.1 to 15.1 hands equivalent to 145 to 155 cm. However, Singh *et al*. (2002) did biometric of 243 Marwari horses in the breeding tract and reported 154.19±0.32 cm height at withers, 153.30±0.36 cm body length, 169.21±0.54 cm heart girth, respectively. Similarly, Gupta *et al*. (2012) did biometric of 66 Marwari horses belonging to the breeding

Table 1. Tier wise estimated breeding value, population and selected individuals' average for the biometric traits of Marwari horses

Parameter	Tier	Population		Selected		Estimated breeding value	
		Male	Female	Male	Female	Male	Female
Wither height (cm)	T-1	153.0±0.0 (1)	150.9±1.2 (9)	153.0±0.0 (1)	150.6±1.6 (7)	0.02±0.16 (19)	0.31±0.25 (16)
	T-2	151.3±1.2 (3)	149.1±0.9 (23)	151.0±2.0 (2)	148.9±1.0 (14)	–0.18±0.32 (7)	–0.33±0.20 (31)
	T-3	151.1±1.8 (10)	150.6±1.1 (11)	153.3±2.2 (6)	150.4±1.3 (7)	0.16±0.27 (23)	0.14±0.24 (19)
	T-4	149.9±0.7 (12)	149.7±0.8 (15)	150.6±0.9 (8)	149.5±1.0 (12)	–0.14±0.15 (21)	–0.34±0.16 (21)
	T-5	150.3±1.3 (3)	150.4±0.7 (15)	149.0±0.0 (1)	151.2±1.5 (6)	–0.28±0.13 (14)	0.04±0.16 (25)
	T-6					0.37±0.17 (7)	–0.02±0.21 (7)
	Effects	Sex, Tier, Sex*Tier: NS		Sex, Tier, Sex*Tier: NS		μ=150.45 cm; Sex, Tier, Sex*Tier: NS	
Body length (cm)	T-1	NA	151.3±1.9 (7)	NA	151.5±2.2 (6)	0.036±0.12 (19)	0.23±0.24 (16)
	T-2	148.0±0.0 (1)	151.0±1.3 (21)	148.0±0.0 (1)	150.5±1.3 (13)	–0.47±0.35 (7)	–0.08±0.23 (31)
	T-3	153.9±2.2 (7)	152.5±1.2 (8)	155.6±2.5 (5)	153.0±1.6 (6)	0.21±0.22 (23)	–0.01±0.15 (19)
	T-4	152.6±0.9 (7)	150.7±1.2 (14)	152.6±0.9 (7)	150.6±1.5 (11)	–0.21±0.11 (21)	–0.25±0.18 (28)
	T-5	150.7±2.2 (3)	150.8±1.2 (11)	148.0±0.0 (1)	151.8±1.4 (6)	–0.25±0.17 (14)	–0.20±0.18 (25)
	T-6					0.08±0.17 (7)	–0.13±0.15 (7)
	Effects	Sex: NS; Tier: NS; Sex*Tier: NS		Sex: NS; Tier: NS; Sex*Tier: NS		μ=151.97 cm; Sex, Tier, Sex*Tier: NS	
Heart girth (cm)	T-1	NA	155.0±5.0 (2)	NA	155.0±5.0 (2)	0.31±0.20 (19)	0.21±0.45 (16)
	T-2	NA	166.6±3.1 (9)	NA	167.0±3.9 (5)	–0.04±0.12 (7)	–0.43±0.25 (31)
	T-3	172.8±5.3 (6)	173.9±1.8 (7)	175.0±7.9 (4)	174.6±2.4 (5)	0.64±0.40 (23)	0.15±0.21 (19)
	T-4	167.3±3.8 (3)	172.6±2.4 (5)	167.3±3.8 (3)	172.0±3.0 (4)	–0.14±0.23 (21)	–0.08±0.23 (28)
	T-5	164.3±4.7 (3)	172.7±2.3 (11)	157.0±0.0 (1)	175.0±3.3 (6)	–0.09±0.20 (14)	0.20±0.28 (25)
	T-6					0.99±0.39 (7)	0.29±0.47 (7)
	Effects	Sex: NS; Tier: NS; Sex*Tier: NS		Sex: NS; Tier: NS; Sex*Tier: NS		μ=169.73 cm; Sex, Tier, Sex*Tier: NS	
Body weight (kg)	T-1	365.0±0.0 (1)	364.7±19.5 (10)	365.0±0.0 (1)	361.0±24.3 (8)	0.92±2.22 (19)	3.87±3.36 (16)
	T-2	361.5±18.4 (4)	357.2±8.7 (20)	343.5±7.5 (2)	355.8±8.3 (12)	-3.93±3.68 (7)	–2.91±1.76 (31)
	T-3	371.8±20.7 (11)	371.9±16.9 (9)	399.7±30.0 (6)	360.0±24.5 (6)	4.22±2.94 (23)	0.10±2.33 (19)
	T-4	352.8±6.9(11)	387.9±12.8(17)	360.8±5.5(8)	401.5±13.8(13)	8.23±1.90 (21)	6.48±2.21 (28)
	T-5	359.7±30.8 (3)	402.5±16.8 (11)	334.0±0.0 (1)		4.60±2.13 (14)	6.18±2.61 (25)
	T-6					10.68±4.11 (7)	8.04±3.75 (7)
	Effects	Sex: NS; Tier: NS; Sex*Tier: NS		Sex: NS; Tier: NS; Sex*Tier: NS		μ=366.30 kg; Sex, Sex*Tier: NS, Tier: S	

Figures in parenthesis indicate number of observations; NA, not available; NS, non-significant (P>0.05); S, significant (P<0.05).

tract and reported 155.42±0.76 cm average height at withers with 142–167 cm range, 156.62±1.05 cm average body length with 142–183 cm range and 174.03±1.34 cm average heart girth with 156–196 cm range. It is evident that the present values of the WH, BL and HG are relatively close to the values reported for Arabian horses (Gharahveysi *et al.* 2008, United States Equestrian Federation 2008). However, they are slightly lower than the one covered in the breeding tract (Singh *et al.* 2002, Gupta *et al.* 2012). It has been established in the literature (Kaura 1961, Edwards 1994, Behl *et al.* 2007, Doniger 2009, Gupta *et al.* 2012, Jun *et al.* 2014, Gadhvi 2017) that the Marwari horses were developed by upgrading of Indian ponies by Arabian horses, the present physical standards of the Marwari horses covered in the study also supports the same and can thus be designated as representing the Marwari horse in pure form. Higher biometric indices of the Marwari horses belonging to the breeding tract could be either due to the preferential breeding for the traits under consideration or it could be due to the crossbreeding with Thoroughbred (Singhvi 2001, Yadav *et al.* 2001, Mehta 2020) to achieve higher biometric indices as the later has an average wither height (WH) of 160.9 cm, body length (BL) of 163.3 cm, chest circumference (CC) of 192.1 cm (Bene *et al*. 2013).

Breeding pattern: It was observed that 66% (44) of the available stallions and 88% (59) of the available mares were used in the breeding programme for the production of next generation. This has resulted in the negligible selection differential for the traits under consideration, except for body weight. The same can be envisaged by comparing the population mean with that of the animals used in the breeding programme which was 150.15 cm vs 150.34 cm for WH, 151.44 cm vs 151.64 cm for BL, 170.02 cm vs 170.50 cm HG and 371.34 kg vs 376.84 kg for BWT, respectively. The analysis of variance indicated that the effect of sex, tier and interaction of sex and tier was non-significant (P>0.05) for the biometric traits under investigation (Table 1). This establishes that the traits under consideration were not among the criteria of selection during the period under study.

Estimated breeding value (EBV): The breeding values have been expressed in relation to the population average as estimated by the Animal Model of Pedigree Viewer Programme. The Best Linear Unbiased Prediction (BLUP) estimate of breeding value for the height at withers (150.45 cm), body length (151.97 cm), heart girth (169.73 cm) and body weight (366.3 kg) pooled over sexes was –0.059 cm, –0.079 cm, 0.096 cm and 3.526 kg with –0.016 cm, –0.056 cm, 0.252 cm and 4.385 kg for stallions and –0.090 cm, –0.096 cm, –0.017 cm and 2.905 kg for mares,

respectively. The effect of sex was non-significant (P>0.05) on the estimated breeding values of the biometric traits under analysis. The effect of tier (generation) was non-significant (P>0.05) on WH, BL and HG but was significant (P<0.05) on body weight of the animals. Though the effect of tier (generation) was non-significant (P>0.05) on height of the animals but the pairwise comparison of the means of different tiers by least significant difference (LSD) test indicated significant (P<0.05) difference in estimated breeding value for height at wither among tier 1 and 4, and tier 3 and 4. Such differences in the pairwise comparison were not observed for body length and heart girth of the Marwari horses. However, the effect of tiers on the estimated breeding value for body weight was significant (P<0.05) indicating that the tiers differed significantly in terms of estimated breeding value for body weight. The pairwise comparison of the means of different tiers by least significant difference test indicated significant (P>0.05) difference in estimated breeding value for body weight among tier 1 and 4, 6; tier 2 and 4, 5, 6; tier 3 and 4, 6; tier 4 and 1, 2, 3; tier 5 and 2 and, tier 6 and 1, 2, 3. The interaction of sex with tier was non-significant (P>0.05). The estimated breeding value in different sex over tiers is given in Table 1.

The present results show that the BLUP estimates of breeding values for the biometric traits, viz. WH, BL and HG, were insignificantly above or below the population average. This appropriately means that WH, BL and HG were not one among the criteria for selection of Marwari horses under study. The effect of sex on the estimated breeding value for WH, BL and HG was non-significant (P>0.05) indicating that no preferential breeding with respect to the sex of the animal has been practiced. Though the effect of tier (generation) was non-significant (P>0.05) on WH of the animals but the pairwise comparison of the means of different tiers by least significant difference (LSD) test indicated significant (P<0.05) difference in estimated breeding value for height at wither of tier 4 with tier 1 and tier 3. The tier 4 (T-4) had the lowest average EBV. The individuals of tier 6 (T-6) were born during the year 2017 to 2020 and are yet to be measured but higher genetic merit reflected in terms of highest estimated breeding value suggests recent selection in favour of height at withers. However, such differences in the pairwise comparison were not observed for body length (BL) and heart girth (HG) of the Marwari horse. Nevertheless, the contribution of sires selected for the production of individuals in T-6 was perceptible in terms of improving the average EBVs over preceding tiers. The effect of tiers on the estimated breeding value for body weight was significant (P<0.05) indicating that the tiers differed significantly in terms of estimated breeding value for body weight. The EBV presented in Table 1 clearly shows that except tier 2, the EBV of BWT had all the time been positive and overall EBV for body weight was 3.53 kg above population mean. This clearly indicated that body weight has received enough favour in breeding programme consistently over a long period spanning from tier 3 to tier 6 in Marwari horses under investigation.

Heritability: The heritability of height at withers, body length, heart girth and body weight was estimated to be 0.396±0.586, 0.370±0.777, 0.507±1.95 and 0.597±0.612, respectively. Larger standard errors were expected because only 50, 35, 12 and 49 records belonging to 11, 9, 4, and 10 sire families were respectively available for WH, BL, HG and BWT. In literature, there are no reports on Marwari horse to compare or contrast the present values. However, the heritability of height at withers (WH) in Murgese horse was reported as 0.24 (Dario *et al.* 2006), in Menorca horse as 0.45 (Sole *et al.*2014) and in Sardinian Anglo Arab Horse as 0.78±0.02 (Giontella *et al.* 2020) as against 0.396±0.586 estimated in present study. Similarly, the heritability of heart girth (HG) in Murgese horse was reported as 0.39 (Dario *et al.* 2006), in Sardinian Anglo Arab Horse as 0.47±0.02 (Giontella *et al.* 2020) and in Iranian Arab horses as 0.263±0.06 as against 0.507±1.95 estimated in present study. Hence, in spite of limited number of records, the present estimates were well within the range of the heritability estimates reported in the literature for respective trait and can therefore be utilised in planning subsequent breeding programmes.

Mass selection: It was observed that nominated mating with the focus on avoiding inbreeding was in practice; an attempt was made to present the difference in the selection based on individual phenotype (mass selection) and the one based on estimated breeding value. The sequential data was rearranged and the animals having the phenotypic value as well as the estimated breeding value were compared and presented in the Fig. 1 for the height at withers.

It is clear that the phenotypic values were higher than the estimated breeding value for almost all individuals (Fig. 1). This was expected because the individual phenotype is an outcome of the genotype plus environmental factors. Further, the heritability of the biometric traits was estimated in the range of medium to high (0.37–0.597). Though, when the heritability is medium to high, the mass selection is expected to give desired success; nevertheless, when correct pedigree relationship of the individuals with known phenotypes is available, estimation of breeding value of individuals with unknown-phenotypes is possible, as well it adds value to the mass selection by making use of the additional information on

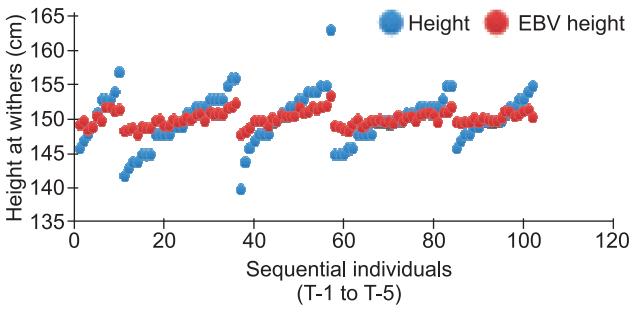

Fig. 1. Height at withers–Breeding value versus phenotypic value over tiers.

performance of related animals. Thus, the Animal Model gives more accurate estimate of breeding value and hence better selection and genetic progress over years. Further, the BLUP estimates of breeding value of the animals, which are yet to attain the adult age and enter into the breeding cycle have also been estimated and can appropriately be utilized for early selection of the individuals for breeding.

Negligible inbreeding over a period 30 years indicated that the Marwari horses under study have been bred to preserve the genetic variation in the breed. The selection for the body weight was effective. For early selection of breeding stock, the estimated breeding value can be utilised. The phenotypic values of the body parameters of Marwari horses under study were very close to that of Arabian horses endorsing the historical relationship between the two breeds. Hence, this institutional herd of Marwari horse can be designated as the most reliable source of the stallions and mares for propagation and conservation of this legendry breed of horse which is getting diluted and declining at a faster rate.

REFERENCES

Behl R, Behl J, Gupta N and Gupta S C. 2007. Genetic relationships of five Indian horse breeds using microsatellite markers. *Animal* **1**: 483–88.

Bene S, Giczi A, Nagy Z, Benedek Z, Szabo F and Polgar J P. 2013. Live weight and body measurement of Hungarian Thoroughbred broodmares. *Journal of Central Europian Agriculture* **14**: 952–62.

Breed Survey 2013. *Estimated Livestock Population Breed Wise.* Ministry of Agriculture and Farmers Welfare, Government of India. New Delhi.

Dario C, Carnicella D, Dario M and Bufano G. 2006. Morphological evolution and heritability estimates for some biometric traits in the Murgese horse breed. *Genetics and Molecular Research* **5**: 309–14.

Doniger W. 2009. *The Hindus: An Alternative History*. Penguin Group, London.

Edwards E H. 1994. *The Encyclopedia of the Horse*. 1st edn. Dorling Kindersley, New York.

Falconer D S. 1981. *Introduction to Quantitative Genetics*. 2nd edn. English Language Book Society / Longman, London.

Gadhvi P. 2017. Historical references to the horse in India. https://www.researchgate.net/publication/341655308 date of access January 8, 2021.

Gharahveysi S, Kashan N E J, Gerami A and Torshizi R V. 2008. Estimation of genetic parameters on conformation traits of the Iranian Arab horses population. *Pakistan Journal of Biological Sciences* **11**: 280–84.

Giontella A, Sarti F M, Biggio G P, Giovannini S, Cherchi R, Pieramati C and Silvestrelli M. 2020. Genetic parameters and inbreeding effect of morphological traits in Sardinian Anglo Arab horse. *Animals* **10**: 1–8.

Gupta A K, Tandon S N, Pal Y, Bhardwaj A and Chauhan M. 2012. Phenotypic characterization of Indian equine breeds: a comparative study. *Animal Genetic Resources* **50**: 49–58.

Harvey W R. 1990. *User's Guide to LSMLMW PC-2 Version Mixed Model Least-squares and Maximum Likelihood Computer Programme,* Mimeograph. Columbus.

IBM Corp. 2019. *IBM SPSS Statistics for Windows, Version 26.0.* IBM Corp., New York.

Jun J H, Cho Y S, Hu H, Kim H M, Jho S, Gadhvi P *et al.* 2014. Whole genome sequence and analysis of the marwari horse breed and its genetic origin. *BMC Genomics* **15**: 1–10.

Kaura R L. 1961. Breeds of horses and donkeys. *Indian Breeds of Livestock (Including Pakistan Breeds)*, pp. 48–57. (Ed.) Kaura R L. Prem Publisher, Lucknow.

Kinghorn B and Kinghorn S. 2015. *Pedigree Viewer*. The University of New England. Retrieved from http://bkinghor.une.edu.au/pedigree.htm.

Lacy R C. 1997. Importance of genetic variation to the viability of mammalian populations. *Journal of Mammalogy* **78** : 320–35.

Livestock Census. 2019. *20th Livestock Census 2019,* All India Report, Ministry of Agriculture and Farmers Welfare, Government of India. New Delhi.

Mehta S C. 2020. Breeding strategies for conservation of indigenous breeds of equines. *International webinar on 'Present and future trends in conservation and breeding technologies to enhance production in indigenous animals'*. Veterinary College and Research Institute, Tirunelveli, Tamil Nadu, India, p. 23–43.

Singh M K and Yadav M P. 2004. The Marwari horse: Pride of India. *Livestock International* **8**: 19–22.

Singh M K, Yadav M P and Mehta N T. 2002. Breed characteristics of Marwari and Kathiawari horses. *Indian Journal of Animal Sciences* **72**: 319–23.

Singhvi N M. 2001. Conservation and management of equines. *Indian Journal of Animal Genetics and Breeding* **23**: 292–95.

Sole M, Cervantes I, Gutierrez J P, Gomez M D and Valera M. 2014. Estimation of genetic parameters for morphological and functional traits in a Menorca horse population. *Spanish Journal of Agricultural Research* **12**: 125–32.

United States Equestrian Federation. 2008. Chapter AR: Arabian, Half-Arabian and Anglo-Arabian Division, Rule Book.

Yadav M P, Ghei J C and Tandon S N. 2001 Equine genetic resources in India and their :conservation. *Indian Journal of Genetics and Breeding* **23**: 296–301.