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Genetic and non-genetic factors influencing birth weight in the Tuli cattle breed of Zimbabwe

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Abstract

Genetic and non-genetic factors were estimated for birth weight in the Tuli cattle breed of Zimbabwe. Performance records ($n = 1154$) were obtained from the Livestock Identification Trust (LIT) for the period (2008–2014) for three farms; X ($n = 494$), Z ($n = 143$) and Y ($n = 517$). We used the Restricted Maximum Likelihood (REML) for fitting the Sire model. The model used the farm, season, sex, year and dam age as fixed effects while the sire was fitted as a random variable. Best Linear Unbiased Prediction (BLUP) was used to predict breeding values (BVs). The mean birth weight was (30.89 ± 0.128). Wet season had higher birth (31.62 ± 0.27) weight than dry season (30.62 ± 0.144); however, the difference was not statistically significant. The other factors, farm, sex, year and dam age had a significant effect ($P < 0.05$) on birth weight. Heritability and repeatability estimates were 0.44 and 0.35, respectively. Based on the results, the high heritability estimate for birth weight suggests that the trait responds well to selection. Sire breeding values ranged from -4.400 to 6.845 with the majority of sires between -2 and 2, showing that there was stabilising selection over the years to minimise both overweights and underweights.

Keywords: Tuli, birth weight, genetic factors, non-genetic factors, estimated breeding values.

1. Introduction

The Tuli is a Sanga breed of cattle believed to be of Tswana descent (Glennels, 2019). It was developed in the 1940s from a research project that utilised what was thought to be a highly productive type of Tswana cattle (Cundiff L, Gregory, Wheeler, & Shackelford, 1994). O'Neill and Frisch (1998) compared the Tuli with the European and Brahaman breeds using Restricted Fragment Length Polymorphism (RFLP), and suggested that the Tuli were of taurine origin.

Birth weight (BWT) is the first vital trait to be recorded in the life of an individual. Its importance is linked to its positive genetic correlation with further live weights as weaning weight and others (Assan, Makuza, Mhlanga, & Mabuku, 2002). BWT has a bearing on calf survival and growth rates and is used in adjusting weights taken at different times during the animal's lifecycle. Studies on piglets have shown that pre-weaning mortality and disease susceptibility are higher in low birth weight piglets (Wolf, Žáková, & Groeneveld, 2008). Conversely, very high BWTs are a direct cause of dystocia.

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The kind and magnitude of genetic properties of the BWT trait should be fully known and understood to establish a viable selection programme. For traits controlled by multiple genes like BWT, estimation of genetic parameters is the same as the estimation of variance components (Meyer, 1984). Total variability in BWT caused by genetic differences between animals on which the measurements were taken is known as heritability. Its estimation seeks to quantify the advantages of a particular trait that superior animals transmit to their offsprings. Variability within the individual component is only affected by the temporary environment between successive performances, while the between individual components is due to the environment affecting the individual permanently (Rao & Bhatia, 2011). Genetic factors affect BWT, so does non-genetic ones such as sex, parity, dam age, season, year, farm, and sire, which are influenced by animal breeding factors to augment the genetic potential of animals. Male calves are known to be born heavier than their female counterparts, while seasons and years with more forage availability are synonymous with heavier BWTs than drought times. Dam age and parity have a traceable trend on their effect on BWT, while different sires produce offspring of varying BWT.

Selection of genetically superior animals is believed to be a sure way of improving these traits, but the full genetic potential is not usually realised because of the effects of non-genetic factors. A study carried out in Zimbabwe by Tawonezvi, Ward, Trail, and Light (1988) showed that Tuli-sired calves are similar to the progeny of British sire breeds for pre-weaning performance. Tuli cows are generally highly fertile. Hetzel (1988) indicated that under high performance environments, the Tuli breed has the most productive females per unit of body weight compared with Brahman, Boran, and other breeds of African origin. It also reached puberty at a younger age than females of both Brahman and Boran (Cundiff et al., 2000). Trail et al. (1977) stated that the Tuli breed had a lower calf mortality rate and a higher calving percentage than both Afrikander and Tswana.

Tuli is known for its high adaptation to hot arid tropics. A study conducted in Australia revealed that it could tolerate heat to levels similar to Brahman × Hereford crosses and better than Hereford (Gaughan, Mader, Holt, Josey, & Rowan, 1999). Tuli genotype offers maximum hybrid vigour; therefore, it is used as a maternal breed in crossbreeding programmes. The breed has a good mothering ability, fewer birth difficulties, high weaning weight and high fertility, even under harsh conditions. Tuli breed has a medium body size with evolutionary adaptability to pests and diseases. In addition, it can tolerant to drought as its body condition can remain fair throughout the year. The breed is docile, making it easy to handle for routine operations and draught. It also matures early, thereby reducing the generation interval and increasing production life. Bulls are productive at 24 months and heifers at twenty. It is a breed of high beef quality with excellent marbling, profoundly tender and juicy meat with low-fat levels, and high feed conversion efficiency. It is suitable for crossbreeding for the exploitation of heterosis. Tulim in South Africa is a cross between Tuli and Limousin. It is, therefore, apparent that there is an optimum breed-specific BWT range to be attained. Genetic and non-genetic factors affect this weight range negatively or positively. It is therefore imperative for both farmers and breeders to know how these factors affect BWT and at what levels. Ward and Dlodlo (1986) reported 31.9 kg Tuli BWT, while Assan (2012) reported 28.41 kg.

BWT is of interest to a breeder since it is genetically correlated to other live weights taken later in life (Assan & Makuza, 2005). It determines the production efficiency of an individual. Optimum BWT is important because it determines an individual's energy reserves, health status, ability to keep the body in a constant condition and the ultimate survival of the calf. Ferrel (1993) reported that low BWT is associated with low survival rates post-partum and low performance in life. It is, therefore, essential to understand factors affecting BWT for evaluation of lifetime performance. Effect of dam age, year of birth, sex and farm have been reported to be significant in different animal species, viz. cattle (Maximillian, Owino, Cyprian, & Reuben, 2012) and goats (Banerjee & Jana, 2010). Intra-uterine foetal growth and ultimately, BWT is influenced by many factors as nutrition, stress, temperature, sex, parity or age of the cow, breed of a dam and others. In a sheep study, Dwyer, Lawrence, Bishop, and Lewis (2003) revealed that BWT significantly affects neonatal development progress. Low BWT lambs suckled less frequently and were slower to stand than high weight lambs. This was attributed to low energy reserves, and increased deaths before or during parturition. Post-natal death was linked to starvation. Several authors have used mixed model analysis as sire models which take into account different fixed effects (Henderson, 1984; Mrode, 2014). Means, variances and covariances are useful for the computation of genetic parameters, namely heritability, repeatability and covariance. The genetic parameters are useful for developing breeding values (BVs) which aid in selection for economic traits (Chikosi, 2005).

The first differences in BWT related to sex were discovered by Haines (1931) early in the twentieth century, revealing males having higher weights than females and that males were rather consistently heavier than females. Work on the influence of sex on the BWT trait reveals inconsistent results due to the influence of breed, time, location and management (Forgarty et al., 2005; Assan, 2012). However, Assan and Makuza (2005) reported that sex had no significant effect on BWT in Sabi sheep. This claim was substantiated by Ali, Ishag, Ibrahim, Magzoob, and Ahmed (2015) who also found out that sex had no significant effect on BWT of Red Angus and Simmental crossbred. However, they reported that males had a higher weight than females at birth. Hafez (1962) attributed this to the anabolic effect of male sex hormones. Male calves have a larger frame than female calves and are therefore heavier at birth. At fertilisation, zygotes with only X chromosomes develop into female foeti, while those with a Y chromosome are males. This differentiation influences hormonal action. In the current study, we evaluated the effects of year of birth, season of birth, sex of calf, dam age, farm and sire on BWT of Tuli. Also, the study estimated that heritability and repeatability for BWT investigated the influence of non-genetic factors on BWT and estimated breeding values for Tuli sires using the Animal Model.

2. Materials and Methods

2.1 Study sites

Perfomance records were obtained from three farms, namely; Jambo, Hirfield and Morrena (Fig. 1). Jambo Farm is located in Tengwe area, 60 km south of Karoi. The minimum temperature is 9 °C, and the maximum temperature is 32 °C. Rainfall average is 750 mm per annum with very hot and humid summers. The veld is sour, and the vegetation consists of *Bachystagia bohem*i and *B. spiciformisi* as dominant tree species, with Terminalia species as subdominant. Other tree species found include *Ziziphus macronata* and *Combretum molle*. Dominant grass species is *Heteropogon contortus* and *Eragrostis racemose*, with *Hyperhenia filipendula* and *Panicum maximum* as subdominant species.

Hirfield Farm is situated 30 km north east of Chegutu town and has the minimum temperature of 8 °C and the maximum temperature of 30 °C Average annual rainfall is 850 mm. The vegetation consists of *Bachystagia bohem*i and *B.spiciformisi* as dominant tree species, with Terminalia species as subdominant. Other tree species found include *Ziziphus macronata* and *Combretum molle*. Dominant grass species is Eragrostis species, *Themeda trianda* and *Heteropogon contortus*. Other species found are *Hyperhenia filipendula* and *Panicum maximum* as subdominant species.

Moreena Farm is situated 45 km northeast of Kwekwe town. The minimum temperature is 7 °C, the maximum temperature is 30 °C, and average annual rainfall is 750 mm annually. The vegetation consists of *Julbernadia globiflora* as the dominant tree species, with *Bachystagia species* as subdominant. Other tree species found on the farm include *Dichycerus cineris* and *Colosfopermun mopane*. Dominant grass species are Eragrostis *species* and *Heteropogon contortus*, while other species found are *Hyperhenia filipendula*, *Panicum maximum* and subdominant species.

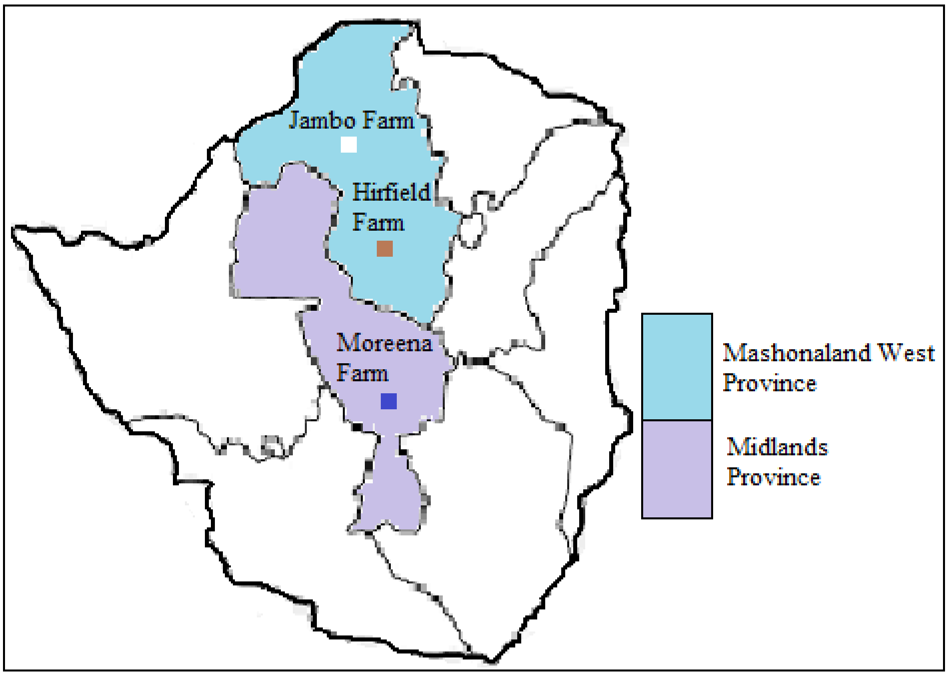

Figure 1. Farms that provided administrative records for the research, Actual names suppressed for Ethical reasons.

2.2 Data source and structure

The data used in the study were obtained from the Livestock Identification Trust (LIT). The data comprised weights recorded from birth to 600 days at varying intervals. A total of 3767 records collected over six years (2008–2014) were acquired from the three farms in different locations, with a total of 45 Tuli sires before data cleaning. The three farms were Jambo (with 1505 records), Hirfielf (814) and Hirfield Farm (1448). Recorded information included animal identity (ANI ID), sex, date of birth (DOB), BWT, sire identity (SID), breed, dam age, calving ease, perfection membership, perfection date, management group and other weights taken at various ages. For this study, some variables were discarded as they were not useful. Only ANI ID, sex, BWT, SID, dam age were retained. Additional variables were added to the records as the year of birth (YOB) taken from DOB and the season of birth (SOB) derived from the month on DOB. Cleaning entailed deleting records with missing BWT, SID and sires with less than five observations. After cleaning, the remaining records were 494 for Jambo Farm, 143 for Moreena Farm and 517 for Hirfield Farm, giving a total of 1154 birth records.

2.3 Data Analysis

2.3.1 Breeding Values

Henderson (1973) derived an algorithm that avoids using $\hat{u}_i = G_0 Z_i' V_i^{-1}\left(y_i - X_i\hat{\beta}\right)$ to compute directly V^{-1} and $\underline{P}$ to get the Best Linear Unbiased estimates of u_i. The new set of equations proposed by Henderson is known as Henderson's mixed model equations (HMME), providing both Best Linear Unbiased Predictor (BLUP) of random effects and General Linear Statistics (GLS) of fixed effects. The BLUP model takes into account the relationship between animals in a population, and in this case, the relationship between sires is essential; therefore, the sire model is used. The mixed model for BWT is represented by:

$$y = X\beta + Z\mu + \varepsilon \tag{1}$$

where:

y is a column vector for phenotypic variation (BWT);

β is column vector for fixed effects (sex, farm, season, year, dam age);

μ is column vector for random effect (sire), it is assumed to be normally distributed with mean 0 and variance $A\sigma_a^2$, $\mu \sim N(0, A\sigma_a^2)$;

A is the numerator relationship matrix;

σ_a^2 is a vector for random residual effect;

ε is a vector for random residual effect;

X and Z are incidence matrices for fixed and animal effects. The solution of linear models of BLUP results in the following MMEs:

$$\begin{pmatrix} X'X & X'Z \\ Z'Z & Z'Z + A^{-1}\lambda \end{pmatrix} \begin{pmatrix} b \\ u \end{pmatrix} = \begin{pmatrix} X'y \\ Z'y \end{pmatrix} \tag{2}$$

A^{-1} is the inverse of matrix A (numerator relation matrix), X' and Z' are the transpose of matrices X and Z respectively.

$$\lambda = \frac{4 - h^2}{h^2} \tag{3}$$

2.3.2 Variance components

The REML procedure developed by (Patterson & Thompson, 1971) was used to estimate genetic parameters since the data was not balanced. Various models were fitted, and the likelihood ratio test (LRT) was used to determine the robust model. The sire model was found to have the least -2 Log-likelihood and was, therefore, used. Dam age, sex, farm, season and year were treated as fixed effects and sire as a random effect. Three factor interactions were considered, but only the farm and sire had significant interactions. The mathematic model used was:

$$Y_{ijkl} = \mu + YR_i + S_j + M_k + D_l + F_m + P_n + SDF_{jmn} + \varepsilon_{ijkl} \tag{4}$$

Where:

Y_{ijkl}, is the effect of the analysed trait (BWT),

μ, is overall mean,

YR_i, is the fixed effect of year of calving,

S_j, is the fixed effect of sex of calf,

M_k, is the fixed effect of season of birth,

D_l, is the fixed effect of dam age,

F_m, is the fixed effect of the farm; P_l is the random effect of sire

γS_{ij}, is an interaction between the year of birth and sex,

γP_{il}, is an interaction between the year of birth and parity,

SP_{ji}, is an interaction between sex of birth and parity,

SDF_{jk}, is an interaction between sex, dam age and farm,

ε_{ijkl} , is the error term ~N (0; 0).

2.3.3 Genetic parameters

Heritability was calculated from REML variance components analysis tests for fixed effects using the following equation:

$$h^2 = \frac{4\sigma_s^2}{\sigma_A^2 + \sigma_e^2} \tag{5}$$

Where;

σ_s^2 -is the sire variance

σ_A^2 -is the additive variance

σ_e^2 -is the residual variance

Repeatabilities were calculated from REML variance components analysis tests for fixed effects using the following equation:

$$R = \frac{V_g + V_{pe}}{SS_s + SS_e} \tag{6}$$

Where;

V_g , is genetic variance

V_{pe} , is the residual component of variance

SS_s , is the sire sum of squares

SS_e , is the residual sum of squares

4. Results and discussion

4.1 Birth weight (BWT)

Mean BWT was 30.86±0.129 kg, with a CV of 14.14%. The BWT had a minimum of 19 kg and a maximum of 45 kg. Heritability and repeatability values were 0.44 and 0.35, respectively. The mean BWT was lower than 33.6 kg, a figure published by (Holloway, Warrington, Forrest, & Randel, 2002) in a research study with Tuli herd in the USA, but higher than 28.41 kg published by Assan (2012) on a study with Matopo Research Tuli herd. Effects of the farm, year of birth, sex, and dam age were significant ($P < 0.05$) on BWT, while the effect of season was not statistically significant. The results are presented in Table 1.

A total of 1155 births, with 600 male calves and 548 females in a ratio of 46 to 54 per cent were recorded. Statistical analysis showed that the mean BWT of male and female calves was 31.48±0.187 kg and 30.18±0.171 kg, respectively (Table 1). Sex had a significant ($P < 0.05$) effect on the BWT of Tuli calves. Male calves were 1.30 kg heavier than the female calves. These results agree with the findings by Abdel, Ali, and Ahmed (1991), who reported that sex had a significant effect on the trait. Ali et al. (2015), however, reported contradicting results in their study with Red Angus and Simmental, which indicated that sex had no significant effect ($P > 0.05$) on BWT. The minimum and maximum dam ages were 1.8 and 14.8 years, respectively, with a range of 13 years. The entire age range was divided into five groups at 3-year intervals. The age group 3–6 years (n = 419) had the greatest range (26 kg) with 19 kg minimum and 45 kg maximum, while age group 12–15 (*n* = 45) had the least observations and range (16 kg) with a minimum of 21 kg and a maximum of 37 kg BWT. The highest (32.13±0.227 kg) and lowest (28.16±0.348 kg) mean BWTs were found in age groups 6–9 (*n* = 350) and 2–3 (n = 144) respectively. The results agree with those of Stefano, Riccardo, and Raimundo (2000), who reported a significant effect of dam age on BWT.

A total of 1148 records were analysed to ascertain the effect of the farm on Tuli BWT, with 488 records from Jambo Farm, 143 from Moreena Farm and 517 from Hirfield Farm. Moreena Farm had the highest mean BWT of 34.98±0.353 kg, Jambo Farm had the least mean BWT of 29.69±0.184 kg, while Y had an intermediate BWT record of 30.82±0.175 kg (Table 1). Analysis of variance (Table 2) indicated that dam age had a significant effect ($P < 0.05$) on BWT. The mean BWT variances for the Jambo Farm, Moreena Farm and Hirfield Farm were 16.56, 17.81 and 15.78, respectively. Similar results were reported by Intan, Ruhul, and Rusli (2014), noting that dam age had a significant effect on production traits.

Table 1: Statistical summary of BWT for Tuli calves

Factors	Level (n)	BWT (kg) ($\pm S.E$)	CV	P-value
Sex	Male (603)	31.48±0.276	14.54	0.001**
	female (551)	30.18±0.171	13.29	
	Mean	**30.83±0.224**	**13.92**	
Year	2008 (132)	29.30±0.413	16.07	
	2009 (133)	32.11±0.395	14.09	
	2010 (86)	30.72±0.393	11.86	
	2011 (223)	30.09±0.262	12.98	0.001**
	2012 (263)	30.09±0.283	14.85	
	2013 (270)	31.34±0.259	13.57	
	2014 (46)	32.61±0.532	11.08	
	Mean	**30.89±0.362**	**13.50**	
Season	wet (274)	31.62±0.276	14.47	0.280n.s
	dry (874)	30.62±0.144	13.94	
	Mean	**31.12±0.210**	**14.21**	
Dam age	>3 (144)	28.16±0.348	14.85	
	>6 (419)	30.40±0.209	14.09	
	>9 (350)	32.13±0.227	13.23	0.001**
	>12 (190)	31.37±0.291	12.79	
	>15 (45)	31.73±0.515	10.88	
	Mean	**30.89±0.318**	**13.17**	
Farm	X (494)	29.69±0.184	13.71	
	Z (143)	34.98±0.353	12.06	0.001**
	Y (517)	30.82±0.175	12.89	
	Mean	**31.83±0.237**	**12.89**	

** Significance at $P < 0.01$. n.s not significant at $P > 0.05$.

4.2 Heritability, Repeatability and Breeding values

In the present study, heritability was estimated at 0.25. In their studies with Tuli, Roman, Wilcox, and Martin (2000) and Assan (2012) found heritability estimates of 0.41 and 0.67, respectively. Also, repeatability was estimated at 0.35, which is almost similar to findings of Roman, Wilcox, and Martin (2000), who estimated repeatability at 0.50. The estimated breeding values ranged from -4.400 to 6.845 (μ = 0) with a calculated mean of -0.024. It was estimated that 35 (78%) of the 45 sires had BVs within the range of -2.00 to 2.00; 4

sires (9%) were above 2, with sire 01-4946DJ having the highest breeding value of 6.845; and 6 sires (13%) were below -2, with sire 10–0465J the lowest BV of -4.400.

Table 2: Summary ANOVA results showing effects of Sex, Farm, SIRE, Season of Birth (SOB), Dam age (D.A), Year of Birth (YOB) and their interaction on BWT

Partial ANOVA components	Model explanatory factors						
	Sex	Sire	D.A	SOB	YOB	Farm	Sex × Sire
DF	1	44	4	1	7	1	34
Mean Squares	490.124	131.267	231.626	36.976	88.716	3.784	17.125
p-value	< 0.0001***	< 0.0001***	< 0.0001***	0.08	< 0.0001***	0.575	0.057
Partial ANOVA components	**Model explanatory factors**						
	Sex×D.A	Sex×SOB	Sex×YOB	Sex×Farm	Sire×D.A	Sire×SOB	Sire×YOB
DF	4	1	6	1	93	20	45
Mean Squares	3.328	7.635	28.252	25.488	11.61	26.524	16.204
p-value	0.893	0.426	0.03*	0.146	0.574	0.002**	0.07
Partial ANOVA components	**Model explanatory factors**						
	Sire×Farm	D.A×SOB	D.A×YOB	D.A×Farm	SOB×YOB	SOB×Farm	YOB×Farm
DF		4	22		5		
Mean Squares		7.703	13.781		46.266		
p-value	M	0.634	0.291	M	0.002**	M	M

***, **, * Significant at 0.1, 1 and 5%. M, removed due to Multicollinearity.

5. Conclusions

The study demonstrated that calving year, dam age, farm and sex significantly influenced BWT in the Tuli herd. Such factors must be considered and adjusted for breeding programmes to select or reject individuals based on genetics. The phenotypic proportion attributed by the environment cannot be passed on from parent to offspring, making adjustments for significant factors mandatory. The estimated breeding values followed a normal distribution with a higher proportion of sires having close to average progeny difference. The results indicate stabilising selection practised over the years on Tuli pedigree herd to produce intermediates, thus avoiding underweights and overweights. The moderate heritability estimate indicates that birth weights can be achieved through both selection and management with some degree of accuracy. Repeatability estimate of BWT observed in the present study was medium, denoting that BWT in Tuli calves is repeatable and hence can be improved through selection.

6. Recommendations

The authors recommend that breeders and farmers alike should take into account non-genetic factors which significantly affect BWT during selection and culling process of breeding stock to avoid making wrong decisions. The breeders are recommended to avoid sires with very high breeding values since this may lead to birth difficulties resulting from overweight calves. Dystocia may cause the death of both the cow and the calf. Similarly, sires with low breeding values must be avoided because their progeny are likely to be underweight, compromising their life long fitness. Farmers buying breeding stock with known breeding values should not use phenotypic appearance when selecting animals. Sires with breeding values above four can be utilised on dams with big frames and potentially high uterine and pelvic capacity to minimise cases of dystocia. The sires might be possessing a high growth rate and high meat yield. Heritability and repeatability estimates should be calculated for different herds from time to time since environmental factors may cause variations. Further research should be done on the correlation between BWT and subsequent live weights such as the 200-day and 400-day weights.

References

Abdel, A., Ali, T., & Ahmed, A. (1991). Effect of some environmental factors on birth weight of Kenana subtype calves of Umbenein and Nashishiba Research Centre Sudan. *Animal Production*.

Assan, N. (2012). Genetic improvement and utilization of indigenous cattle breeds for beef production in Zimbabwe: past, present and future prospects. *Scientific Journal of Agricultural*, *1*(1), 1-13.

Assan, N., & Makuza, S. (2005). The Effect of Non-genetic Factors on Birth Weight and Weaning Weight in Three Sheep Breeds of Zimbabwe. *Asian-Australasian Journal of Animal Sciences*. doi:10.5713/ajas.2005.151

Assan, N., Makuza, S., Mhlanga, F., & Mabuku, O. (2002). Genetic Evaluation and Selection Response of Birth Weight and Weaning Weight in Indigenous Sabi Sheep. *Asian-Australasian Journal of Animal Sciences*, *15*(12), 1690–1694.

Banerjee, S., & Jana, D. (2010). Factors affecting birth weight of Sirohi goat kids reared in hot and humid climate of west Bengal. *World Applied Science.*, *9*(12), 1379–1382.

Borg, R., Notter, D., & Kott, R. (2009). Phenotypic and genetic associations between lamb growth traits and adult ewe body weights in western range sheep. *Animal Science*, *87*, 3506–3514.

Cundiff, Gregory, T., Wheeler, S., Shackelford, M., Koohmaraie, H. C., Freetly, & Lunstra, D. (2000). *Preliminary results from Cycle V of the cattle germplasm evaluation program at the Roman L. Hruska U.S. Meat Animal Research Center.* Beef Cattle Research Program, GPE Progress Report No. 19:1–12.: USDA-ARS, RLHUSMARC.

Cundiff, L., Gregory, K., Wheeler, L., & Shackelford, S. A. (1994). Carcass and meat characteristics of Tuli, Boran, Brahman, Belgian Blue, Piedmontese, Hereford and Angus breed crosses in the cattle germplasm evaluation program. *Proceedings of the World Congress on Genetics applied to Livestock Production* (pp. 272–275). Guelph, Canada: wcgalp.org/. Retrieved from http://www.wcgalp.org/system/files/proceedings

Dwyer, C., Lawrence, A., Bishop, S., & Lewis, M. (2003). Ewe-lamb bonding behaviours at birth are affected by maternal under nutrition in pregnancy. *British Journal of Nutrition*, *89*(1), 123–136.

Ferrel, C. (1993). *Factors influencing fetal growth and birth weight in cattle.* Roman L. Hruska US: Meat Animal Research Centre, Paper 132.

Forgarty, A., Ingham, A., Gilmour, A., Cummins, C., Gaunt, D., Stafford, E., . . . Banks, F. (2005). *Genetic evaluation of crossbred lamb production. Breed and fixed effects for birth and weaning weight of first-cross lambs, gestation length, and reproduction of base ewes.* Clayton South, Australia.

Gaughan, J. B., Mader, T. L., Holt, S. M., Josey, M., & Rowan, J. (1999). Heat Tolerance of Boran and Tuli Crossbred Steers. *Animal Science*, 2398–2405.

Glennels, K. (2019, Nov). *Tuli Cattle, Beef production in South Africa*. Retrieved from South Africa's showcase of our collective heritage: http://southafrica.co.za/tuli-cattle.html

Gregory, E. K., Cundiff, L. V., & Koch, R. M. (1995). Genetic and phenotypic (co)variances for growth and carcass traits of purebred and composite populations of beef cattle. *Journal of Animal Science, 73*(7), 1920–1926. doi: https://doi.org/10.2527/1995.7371920x

Hafez, E. (1962). *Reproduction in farm animals. Lea and Febiger.* Philadelphia.

Haines, G. (1931). A statistical study of the relation between various expressions of fertility and vigor in the guinea pig. *Journal of Agricultural Research*, 123–164.

Henderson, C. (1973). Sire evaluation and genetic trends, In: Proceedings of the animal breeding and genetics symposium in honor of Dr J Lush. *American Society Animal Science* (pp. 10-41). Champaign, IL: American Dairy Science Association.

Henderson, C. (1984). *Applications of Linear Models in Animal Breeding.* Guelph, Canada: University of Guelph.

Hetzel, D. (1988). Comparative productivity of the Brahman and some indigenous Sanga and Bos indicus breeds of East and Southern Africa. Animal Breeding Abstracts. *Animal Production*, *56*(4), 243-255. Retrieved from https://cgspace.cgiar.org/handle/10568/66910

Holloway, J., Warrington, B., Forrest, D., & Randel, R. (2002). Growth and Performance of F1 Tropically Adapted Beef Cattle Breeds x Angus in Arid Rangeland, Texas Agricultural Experiment Station, Uvalde, Department of Animal Science. *Senepol Symposium.* St. Croix.

Intan, S., Ruhul, A., & Rusli, N. (2014). Effect of Some Non-Genetic Factors on Birth Weight and Pre-Weaning Growth Pattern in Kedah-Kelantan Calves. *Journal of Tropical Resources and Sustainable Science, UMK.* Retrieved from https://www.semanticscholar.org/paper/Effect-of-Some-Non-Genetic-Factors-on-Birth-Weight-Fuad-Amin/86b8e008a227a4d67209d899e5505e743a8c9466

Maximillian, M., Owino, J., Cyprian, E., & Reuben, O. M. (2012). Factors affecting pre and post-weaning growth of six cattle breed groups at Songa Research station in Rwanda. *Livestock Research for Rural Development, 24*(4). doi: http://www.lrrd.org/lrrd24/4/manz24068.htm

Meyer, K. (1984). Estimates of genetic parameters for milk and fat yield for the first three lactations in British Friesian cows. *Anim. Prod, 38*, 313-332. Retrieved from http://www.scielo.br/scielo.php?script=sci_nlinks&ref=000107&pid=S1415-4757200000010002100020&lng=en

Mrode, R. (2014). *Linear models for the prediction of animal breeding values.* London, UK: CABI. Retrieved from https://www.cabi.org/bookshop/book/9781780643915/

O'Neill, C. J., & Frisch, J. E. (1998). Lactation; growth and efficiency; meat quality; role of exotic breeds in the tropics; design of village breeding programmes. *World Congress of Genetics Applied to Livestock Production digital archive* (pp. 223-226). Armidale, Australia: wcgalp.org/.

Patterson, H. D., & Thompson, R. (1971). Recovery of interblock information when block sizes are unequal. *Biometrika, 58*, 545–554.

Rao, A., & Bhatia, V. (2011). *Estimation of Genetic Parameters.* New Delhi: Indian Agricultural Statistics Research Institute.

Stefano, B., Riccardo, B., & Raimundo, M. (2000). Environmental effects on birth and weaning weights of Gyr and Guzera cattle in 1he northeast of Brazil. *Ciencia Agronomica, 31*, 65–74.

Tawonezvi, H., Ward, H., Trail, J., & Light, D. (1988). Evaluation of beef breeds for rangeland weaner production in Zimbabwe. I. Productivity of purebred cows. *Animal Production*, 341–351.

Trail, J., Buck, N., Light, D., Rennie, T., Rutherford, A., Miller, M., . . . Capper, B. (1977). Productivity of Afrikaner, Tswana, Tuli and crossbred beef cattle in Botswana. *Animal Production, 24*, 57-62.

Ward, H., & Dlodlo, S. (1986). *Post weaning growth and carcass characteristics of crossbred cattle. Paper presented to the Zimbabwe Society for Animal Production, "Productivity of crossbred beef cattle" .* Bulawayo, Zimbabwe: Matopos Research Institute.

Wolf, J., Žáková, E., & Groeneveld, E. (2008). Within-litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. *Livestock Science, 115*(2-3), 195-205. doi: https://doi.org/10.1016/j.livsci.2007.07.009