Indian Journal of Animal Sciences **89**(7): 752–757, July 2019/Article
https://doi.org/10.56093/ijans.v89i7.92038

Genetic evaluation including maternal effects in Large White Yorkshire × *desi* crossbred pigs under hot and humid conditions of India

P JAYASREE[1], S N SIVASELVAM[2], R VENKATARAMANAN[3], S MEENAKSHI SUNDARAM[4], K V GOWRIMANOKARI [5], V ARTHY[6] and D BALASUBRAMANYAM[7]

Tamil Nadu Veterinary and Animal Sciences University, Kattupakkam, Tamil Nadu 603 203 India

Received: 15 August 2018; Accepted: 20 November 2018

ABSTRACT

A study was conducted to evaluate the individual and sow performance traits of Large White Yorkshire × *desi* crossbred pigs at All India Co-ordinated Research Project on Pigs (AICRP), Kattupakkam. The genetic groups studied were 50% LWY (100% LWY × 100% *desi*), 50% LWY *inter se* (50% LWY 50% *desi* × 50% LWY 50% *desi*), 75% LWY (100% LWY × 50% LWY 50% *desi*) and 75% LWY *inter se* (75% LWY 25% *desi* × 75% LWY 25% *desi*). The (co)variance components for different traits were estimated by restricted maximum likelihood method (REML). The average inbreeding in the whole population was 5.4%. Maternal genetic and common litter effects were important random sources of variation in individual traits. The least-squares mean for birth weight (BW), weaning weight (WW), average daily gain up to weaning (ADG), market weight (MW), pre-weaning mortality (PWM), age at first farrowing (AFF), litter size at birth (LSAB), litter weight at birth (LWAB), litter size at weaning (LSAW), litter weight at weaning (LWAW) and farrowing interval (FI) were 1.079 kg, 7.906 kg, 142.238 g, 8.4%, 62.208 kg, 456.829 days, 197.994 days, 6.792, 8.174 kg, 6.347 and 60.649 kg, respectively, and the direct heritability obtained through the best model were 0.069, 0.015, 0.012, 0.031, 0.291, 0.019, 0.173, 0.257, 0.076 and 0.157, respectively. The repeatability estimates for LWAB, LSAW, LWAW and FI were 0.265, 0.258, 0.263 and 0.762, respectively. The 75% LWY were better in terms of production and reproduction traits and the high heritability for litter traits provided good scope for improvement.

Key words: Crossbred pigs, *Desi*, Genetic parameters, India, Large white yorkshire, Maternal influence, Selection

Full benefits from crossbreeding, a useful tool for increasing the efficiency of swine production, can be gained by careful selection among and combination of available breeds. Large White Yorkshire (LWY), Landrace, Hampshire, Tamworth, Durocare are some of the important exotic breeds used for crossbreeding in India (Anonymous 2002). Large White Yorkshire is known for important economic traits like growth and litter size and hence used in various parts of the country (Jayarajan 1985). Akanno *et al.* (2013) reports Large White Yorkshire and Landrace as the breeds with good production and reproduction potential. In India, literature on performance of exotic breeds and their crosses is in general less and available mainly from Kerala, Andhra Pradesh, Madhya Pradesh and North Eastern states (Kumar *et al.* 2013, Ganesan *et al.* 2013, Kaushik *et al.* 2013, Rokde *et al.* 2013, Mondal and Kumar 2015, Prakash *et al.* 2008). Moreover, traits evaluated in these studies were birth weight, weaning, weight and litter sizes at birth and weaning and estimates of genetic parameters were based on half-sib correlation through least-squares method of estimation. Studies have emphasised the importance of other random sources of variation such as maternal genetic, maternal permanent environmental, individual permanent environmental and common litter effects in estimating (co)variance components, without which there is a possibility of overbias in estimates (Chimonyo *et al.* 2006, Ilatsia *et al.* 2008, Akanno *et al.* 2013). Evaluating the performance of various crossbreds in different regions is important to understand the adaptability of the composite breeds, suggesting suitable breeding plans and optimise the apt blood levels for best production and reproduction performance. The present study was done to evaluate the performance of various genetic groups of LWY × desi crossbreds and estimate (co)variance components by including maternal effects.

Present address: [1]Veterinary Assistant Surgeon (jayavet68 @gmail.com), [2]Principal (snsivaselvam @hotmail.com), [3]Associate Professor (venkyvet @gmail.com), Instructional Livestock Farm compex, Madhavaram Milk Colony, Chennai. [4,7]Professor (srsundha22@gmail.com, dbsagb @gmail.com), [5]PhD Scholar (Manokarivet8@gmail.com), [6]Teaching Assistant (arthyvedassalam@gmail.com).

MATERIALS AND METHODS

Information on pedigree, sex, production, reproduction and disposal available from 1993 to 2016 (24 years) at the ICAR-All India Co-ordinated Research Project on Pigs, Pig breeding unit, Post Graduate Research Institute in Animal

Sciences (AICRP), Kattupakkam, were used for the study. The various crossbred groups were 50% LWY (100% LWY × 100% *desi*), 50% LWY *inter se* (50% LWY 50% *desi*× 50% LWY 50% *desi*), 75% LWY (100% LWY × 50% LWY 50% *desi*), 75% LWY *inter se* (75% LWY 25% *desi*× 75% LWY 25% *desi*).

The climate in the region is hot and humid. The mean minimum temperature varies from 19.69°C in January to 28.14°C in May. The mean maximum temperature varies from 27.27°C in January to 37.53°C in May. The relative humidity ranges from 51.19 to 66.65% and is highest during December. The average rainfall recorded in the region is 105.23 cm/year. Males and females were selected based on litter size at birth (7 and above), litter size at weaning (best 25%), number of teats (minimum 6 pairs), weaning weight and 8-month body weight. Early selection was carried out based on weaning weight (best 25%) and final selection was based on weight at eight months of age, from a particular litter, either males or females were selected.

The different production and reproduction traits studied were birth weight (BW), weaning weight (WW), pre-weaning average daily gain (ADG), pre-weaning mortality (PWM), age at first farrowing (AFF), farrowing interval (FI), litter size at birth (LSAB), litter weight at birth (LWAB), litter size at weaning (LSAW) and litter weight at weaning (LWAW).

Period of birth, season of birth, sex, parity, genetic group and litter size at birth were considered as fixed effects for all individual traits described above and weaning age was included for weaning weight in addition to the above sources of variation. Period and season of farrowing was used instead of birth for sow performance traits, in which, parity, litter size at birth, weaning age were the additional sources of variation.

The inbreeding coefficient (F) of each individual, was calculated (Wright 1931) as path coefficient. In order to understand the effect of level of inbreeding, values of F was included as a fixed class with 5 levels along with other non-genetic factors.

Statistical analysis: Single trait analysis was done by fitting a general linear model (GLM) to study the effect of various non-genetic factors (fixed factors) on each production and reproduction trait. Pair-wise comparison for subclass means within each fixed effect was done by Duncan's multiple range test. (Co)Variance components for different production and reproduction traits were estimated by restricted maximum likelihood method (REML) using WOMBAT program (Meyer 2007), by fitting an animal model for all traits. Direct genetic effect, maternal genetic effect, maternal permanent environmental effect, common litter environmental effect were considered as random effect in addition to significant fixed effects, as obtained from the GLM. The following models were used for the estimation of (co) variance components.

Individual traits

$Y = Xb + Z_a a + e$ (Model 1); $Y = Xb + Z_a a + Z_m m + e$ (Model 2); $Y = Xb + Z_a a + Z_{mp} mp + e$ (Model 3); $Y = Xb + Z_a a + Z_c c$ (Model 4); $Y = Xb + Z_a a + Z_m m + Z_{mp} mp + e$ (Model 5); $Y = Xb + Z_a a + Z_m m + Z_c c + e$ (Model 6); $Y = Xb + Z_a a + Z_{mp} mp + Z_c c + e$ (Model 7); $Y = Xb + Z_a a + Z_m m + Z_p mp + Z_c c + e$ (Model 8)

Sow performance traits

$Y = Xb + Z_a a + Z_p pe + e$ (Model 9)

where Y, N × 1 vector of records; b, fixed effects in the model with association matrix × ; a, vector of direct genetic effects with the association matrix Z_a; m, vector of maternal genetic effects with the association matrix Z_m; mp, vector of maternal permanent environmental effects with the association matrix Z_{mp}; c, vector of common litter environmental effects with the association matrix Z_c; pe, vector of permanent environmental effects of sow with the association matrix Z_{pe}; and e, vector of residual (temporary environment) effect. The fixed effects included in the model were those only found to be significant effect in the initial GLM.

Log likelihood ratio tests (LRT) were carried out to identify the best model for each trait. Estimates of breeding values (EBV) for different production and reproduction traits were obtained by best linear unbiased prediction (BLUP), for which (co)variance components obtained from best model was used. Henderson's mixed model equations (Henderson 1975) were solved to obtain best linear unbiased estimates (BLUE) of fixed effects and BLUP values of EBV. The genetic and phenotypic trends were depicted using the breeding values and phenotypic values for birth weight, weaning weight, litter size at birth and litter size at weaning.

RESULTS AND DISCUSSION

The descriptive details of the data set, inclusive of raw mean, standard error and coefficient of variation for individual and sow performance traits in LWY × *desi* pigs are presented in Tables 1 and 2. Other than pre-weaning mortality which being a binary trait, the most variable trait among individual performance traits was market weight (CV=29.82%), while litter weight at birth was more variable among the sow performance traits (CV=35.20%). The least square means and standard errors for various genetic groups studies are presented in Tables 3 and 4. The individual traits of birth weight, weaning weight, pre-weaning average daily gain and market weight were well within the range of studies reported for LWY × desi in India (Prakash *et al.* 2008, Cauveri *et al.* 2009, Kumari and Rao 2010, Ganesan *et al.* 2013). The market weight obtained in the present study was lower than that reported by Gopinathan and Usha (2011) in LWY crosses at Mannutty, Kerala.

Period, season, sex, parity, litter size at birth, inbreeding were significant on production traits. Season was significant for a few traits such as WW and AFF. The males were heavier than females and BW and MW increased with period. The average inbreeding in the whole population was 5.4% and that for inbred population was 8.7%.

The performance of 50% and 75% LWY are presented in Table 5. Birth weight, weaning weight, ADG, LSAB and LSAW increased with increased blood level of LWY and the maximum birth weight was attained in the genetic group 75 *interse*. Similarly, pre-weaning mortality was also minimum in the stabilized population of 75 LWY *interse*. The superiority of 75% LWY was evident with almost 2 piglets more compared to the 50% LWY.

Inbreeding was a significant source of variation for birth and weaning weight. Birth weight decreased from I class with zero % inbreeding to IV class with 6.125 to 12.5% inbreeding, indicating a depressive effect. However, a slight increase in the fifth group of inbreeding > 12.5% was noticed. A similar trend was also observed for market weight. Gowrimanokari *et al.* (2018) observed nonsignificant influence of inbreeding on most traits in LWY pigs.

Table 1. Descriptive statistics for individual traits in crossbred (LWY×*desi*) pigs

Trait	Birth weight (kg)	Weaning weight (kg)	Pre-weaning ADG (g)	Market weight (kg)	Pre-weaning mortality (%)
No. of records	4833	3937	3968	219	4320
No. of animals in pedigree	4083	4083	4191	685	4571
No. of sires	216	210	216	157	209
No. of dams	514	488	496	285	494
Mean±SE	1.16± 0.004	8.03± 0.030	143.03± 0.645	65.54± 1.32	7.0± 0.4
SD	0.253	1.901	40.64	19.54	25.1
CV (%)	21.81	23.67	28.41	29.82	358.57
Variance	0.064	3.615	1652.087	381.822	632.0
Range	0.50–2.26	5.0–14.5	41.19–255.37	30–135	0–100

Values for litter size at birth and litter size at weaning were almost similar to earlier studies at Andhra Pradesh (Prakash *et al.* 2008). Effect of parity was significant for litter size at birth and the number increased with parity. In the first parity, lower performance may be due to the fact that uterus is not fully developed. Significant effect of parity on litter traits was reported by other authors also (Jayarajan 1985).

Even though heterosis is expected to be maximum in the 50% LWY × *desi*, the increased blood level of LWY in 75% LWY has brought about improvement in traits like, BW, WW, ADG, LSAB and LSAW for which the breed is known for. Moreover, the breeding program was to initially produce LWY 50% crossbreds and then select amongst the 75% LWY crossbred pigs produced through *interse* mating.

The animals for 50F1 (2001–2003), 75F1 (2002–2003), 50 *interse* (2004–2008), and 75 *interse* (2004–2016) were born chronologically and effect of selection and improvement in management over the period could have contributed to better performance of the *interse* animals with lower heterosis, born in later generations. Pre-weaning mortality is an adaptability trait and one of the main advantages of crossbred LWY is the adaptability of *desi* pigs in these animals compared to the purebred LWY. However, in the present study, 75% crossbreds with lower heterosis had better survivability compared to the 50% LWY crossbreds. The survivability of piglets mainly depends upon management factors and improvement of management practices over the period could be the possible reason as LWY 75% animals have been maintained during the later periods of the study. Birth weight included as fixed class indicated better survivability in higher birth weight class >2.0 kg.

Table 2. Descriptive statistics for sow performance traits in crossbred (LWY×*desi*) pigs

Trait	Litter size at birth	Age at first farrowing	Litter weight at birth (kg)	Litter size at weaning	Litter weight at weaning (kg)	Farrowing interval (days)
No of records	600	369	597	547	446	209
Mean±SE	7.75±0.084	460.44±5.652	8.58±0.124	6.85±0.099	59.49±0.713	205.55±1.696
SD	2.051	108.562	3.020	2.314	15.056	24.525
CV (%)	26.46	23.58	35.20	33.78	25.31	11.93
Variance	4.207	11785.758	9.124	5.352	226.679	601.48
Range	2–13	278–803	0.7–18.84	1–13	33.10–125.40	174–343

Table 3. Mean performance of LWY crosses—Individual performance traits

Genetic group	Birth weight	Weaning weight	Pre ADG	Pre weaning mortality	Market weight
50% LWY	$0.954±0.022^d$	$7.452±0.199^c$	$138.765±3.782^c$	$0.114±0.034^a$	–
50% LWY *inter se*	$1.074±0.014^c$	$7.992±0.128^a$	$141.813±2.483^b$	$0.117±0.027^a$	56.797±4.609
75% LWY	1.190±0.022	$7.787±0.182^c$	$137.723±3.520^c$	$0.080±0.031^b$	72.184±7.491
75% LWY *inter se*	$1.192±0.009^a$	$8.304±0.075^b$	$146.822±1.451^a$	$0.031±0.022^b$	64.093±3.356

Table 4. Mean performance of LWY crosses-sow performance traits

Genetic group	AFF	FI	LSAB	LSAW	LWAB	LWAW
50% LWY	445.452±28.303	197.605±12.756	6.033±0.504	$5.452±0.565^{bc}$	$6.893±0.618^c$	54.557±3.408
50% LWY *inter se*	463.179±16.033	189.841±7.172	6.127±0.322	$5.731±0.343^c$	$7.154±0.396^c$	63.770±2.105
75% LWY	462.212±21.593	–	7.773±0.514	$7.338±0.512^{ab}$	$9.422±0.630^b$	56.665±2.940
75% LWY *inter se*	462.202±9.701	206.534±5.853	$7.877±0.194^a$	$7.471±0.199^a$	$10.016±0.242^a$	65.741±1.334

However, reproductive fitness traits of AFF and FI were better in the 50 F1 compared to 75% LWY. The breeding program followed by AICRP to avoid overlapping generations in the 75% LWY could be the possible reason for this. Animals were used only up to third farrowing in the 75% LWY crosses after which they were disposed off. Compared to indigenous pigs, the performance of Large White Yorkshire crosses in this study showed superior performance with respect to individual and sow performance traits (Phookan *et al.* 2006).

The (Co)variance components obtained from the best model of fit for individual and sow performance traits are presented in Tables 5 and 6, respectively. The sixth model including additive genetic, maternal genetic and common litter effect was found to be the best for BW, WW and ADG while the basic animal Model 1 was best fit for MW and Model 4 with animal and common litter effect was best for PWM. Thus inclusion of maternal effects is important to avoid bias in estimation of (co)variance components. All the sow performance traits were analysed using the repeatability model as maternal influence was deemed to diminish as age advances and assumed to be negligible for the sow at the time of farrowing.

The heritability of birth and weaning weight was lower than most of the values reported in India. The higher estimates of most of the studies on birth weight and weaning weight could be due to the method of estimation, which was full sib or half sib correlation (Kalitha *et al.* 2006 in Hampshire; Ganesan *et al.* 2015 in LWY 50% crossbred pigs; Mondal and Kumar 2015 in Landrace crossbred). The paternal half-sib method could lead to overestimation of heritability (Akanno *et al*. 2013). Dufranse *et al*. (2014) obtained very high estimates of 0.25 and 0.42 for birth and weaning weight in crossbred pigs, in spite of using a model including animal, maternal and common litter effects. However, the authors have attributed the high estimate of birth weight to variation in time of recording of weight at birth. The lower heritability values of birth weight were in agreement with earlier studies in different genetic groups of exotic pigs (Kaufmann 2000, Hermesch *et al.* 2001, Arango *et al*. 2006, Banville *et al.* 2015). The methodology used in these studies was similar to the present study. As seen in the present study, the model with direct additive, maternal additive and common litter environmental effects were obtained as best model by Hermesch *et al*. (2001) in Large White pigs and Mondal and Kumar (2015) in Landrace crossbreds.

The direct heritability estimate of PWM was comparable with that reported in the review of Akanno *et al.* (2013). Other reports indicated lower values of heritability for PWM (Lund *et al*. 2002, Arango *et al.* 2006, Aimonen and Uimari 2013, Dufranse *et al.* 2014).

Maternal heritability for BW, WW and ADG were 0.161, 0.085 and 0.062. Studies have proven that ignoring maternal effects can lead to biased estimates (Chimonyo *et al.* 2006, Ilatsia *et al.* 2008, Akanno *et al.* 2013). In this study,

Table 5. Estimates of (co) variance components and heritability—Individual traits

Best Model	σ^2_e	σ^2_p	σ^2_a	σ^2_m	σ^2_{mp}	σ^2_c	h^2±SE	h^2_m±SE	log L
					Birth weight				
6	0.026	–	0.004	0.009	–	0.019	0.069±0.051	0.161±0.040	5470.998
					Weaning weight				
6	1.669	3.126	0.046	0.265	–	1.147	0.015±0.042	0.085±0.036	–3427.196
					Pre-weaning average daily gain				
6	634.890	1170.500	13.487	72.178	–	449.920	0.012±0.038	0.062±0.032	–14932.580
					Market weight				
1	208.760	294.440	85.675	–	–	–	0.291±0.181	–	–718.583
					Pre-weaning mortality				
4	0.055	0.062	0.002	–	–	0.005	0.031±0.023	–	–6060.194

σ^2_e, Error variance; σ^2_p, phenotypic variance; σ^2_a, direct additive genetic variance; σ^2_m, maternal genetic variance; σ^2_{mp}, maternal permanent environmental variance; σ^2_c, common litter environmental variance; h^2, direct heritability; h^2_m, maternal heritability; log L – Log likelihood; SE, Standard error. Best fit model is shown in bold letters. The dashes indicate that the effect was not included in the model.

Table 6. Estimates of (co)variance components, heritability and repeatability for sow performance traits

Trait	σ^2_e	σ^2_p	σ^2_a	σ^2_{pe}	h^2±SE	r±SE
Age at first fertile farrowing	6458.100	6582.700	124.590	–	0.019±0.075	
Litter size at birth	0.0356	4.157	2.492	1.629	0.600±0.097	0.991±0.001
Litter weight at birth	5.598	7.620	1.320	0.702	0.173±0.080	0.265±0.066
Litter size at weaning	3.874	5.218	1.344	0.000	0.257±0.095	0.258±0.071
Litter weight at weaning	90.057	122.15	9.283	22.811	0.076±0.078	0.263±0.081
Farrowing interval	95.228	400.250	62.976	242.040	0.157±0.174	0.762±0.074

σ^2_e, Error variance; σ^2_p, phenotypic variance; σ^2_a, direct additive genetic variance; σ^2_{pe}, permanent environmental variance; h^2, heritability; r, repeatability; SE, standard error.

maternal genetic and maternal permanent environmental effects were included and model with best fit was used to estimate the genetic parameters, so as to get unbiased estimates. Maternal effect was significant for BW, WW and ADG. Similarly most of the studies (Ilatsia *et al.* 2008, Dufranse *et al.* 2014, Banville *et al.* 2015) showed that maternal effect is prolonged with diminishing effect until weaning after which it deteriorates. Dufranse *et al.* (2014) explains this as a result of it appeared that genetic influence of the dam was important on weight until weaning, but decreased as the direct influence of the piglet genotype increased. The maternal heritability for birth weight (0.05) and WW in this study were comparable to other studies (Grandinson *et al.* 2002, Arango *et al.* 2006, Akanno *et al.* 2013). As observed by Banville *et al.* (2015), the present evaluation also indicated a slightly higher maternal heritability for birth weight than direct heritability.

Maternal heritability of WW was lower than that for BW in the present study indicating the diminishing effect with age. Results contrary to this were observed by Akanno *et al.* (2013) in his meta-analysis, where maternal effect increased with age. In an animal model context, maternal estimate depends largely on the data structure and the model used for analysis (Meyer 1992). The unexpected results seen by Akanno *et al.* (2013) was attributed to data structure used in the primary studies included in their metaanalysis.

Litter-bearing species usually have a large number of non-additive relationships (Norris *et al*. 2007) and common litter effects should be accounted for in the model for analysis of traits (Chimonyo *et al*. 2006, Chimonyo and Dzama 2007, Ilatsia *et al*. 2008, Akanno *et al*. 2013). The common litter environmental effects were found to be a significant source of variation on all the individual traits studied except MW and the effects were slightly decreasing as age advances. Similar findings for the significance of common litter environmental effects were observed by Dufranse *et al*. (2014) and Mondal and Kumar (2015), indicating that the growth of piglets are mainly affected by its litter mates and the diminishing effect was due to increase in direct heritability with age. Owing to influence of own additive effect increased as advancing age and the nonsignificance of maternal effect from weaning indicates that can go for individual selection rather than other selection criteria to improve the trait of interest.

LSAB and LSAW, in spite of being a fitness trait had a very high heritability estimate of 0.6 as observed in other earlier reports from India (Jayarajan 1985, Prakash *et al.* 2008, Rokde *et al.* 2013, Devi and Jayashankar 2014). The main reason is the method of estimation where animal and individual permanent environmental effects were the only sources of random variation included. Other studies including these sources report lower values of heritability for the trait (Chimonyo *et al.* 2006, Imboonta *et al*. 2007, Fernandez *et al*. 2008, Chansomboon *et al*. 2010, Dube *et al*. 2012, Paura *et al*. 2014).

The estimates of heritability for litter weight at birth were moderate and the value was almost similar to the findings of earlier studies (Chimonyo *et al.* 2006, Wolf *et al*. 2008, Akanno *et al.* 2013). The heritability and repeatability of litter weight at weaning were low and this was in agreement with the findings of Chansomboon *et al.* (2010), Dube *et al.* (2012), Akanno *et al*. (2013). Repeatability for the repeatable traits, viz. FI, LSAB, LWAB, LSAW and LWAW were 0.762, 0.991, 0.265, 0.258 and 0.263.

The heritability and repeatability of farrowing interval was moderate and higher compared to the range of estimates reported earlier (Kumari and Rao 2010, Das *et al*. 2005, Akanno *et al*. 2013, Kiszlinger *et al*. 2015) in various genetic groups of pigs. Again inclusion of common litter could yield lower estimates for the trait. In general, the estimates of heritability obtained for LSAB, LSAW and FI were higher compared to studies in purebred LWY. The heterogenous nature of the crossbred population could be the probable cause for higher genetic variability leading to higher heritability compared to purebred LWY in this study. Several experiments have shown higher heritability in crossbreds than their constituting purebreds (Ehlers *et al.* 2005).

The genetic trend estimated as regression of breeding value over years for BW, WW, PWM, LSAB, and LSAW were –0.00004 kg, 0.0025 kg, –0.000005 and 0.0222 kg, respectively. The positive genetic trend for LSAB could be due to the higher genetic variability in the trait.

To conclude, the performance evaluation of crossbred LWY pigs indicated better adaptability and productivity in 75% LWY under the given condition. Genetic parameter estimates were comparatively lower for growth traits for which alternate methods of selection has to be thought of, while there is scope for improvement in LSAB and LSAW by virtue of their greater heritability values.

ACKNOWLEDGEMENTS

The authors acknowledge the All India Co-ordinated Research Project on Pigs (AICRP), PGRIAS, Kattupakkam for providing access to their data. We thank the Director, Centre for Animal Production Studies and Dean, Madras Veterinary College, Chennai, Tamil Nadu Veterinary and Animal Sciences University for the facilities provided.

REFERENCES

Aimonen M L S and Uimari P. 2013. Heritability of sow longevity and lifetime prolificacy in Finnish Yorkshire and Landrace pigs. *Agricultural and Food Science* **22**: 325–30.

Akanno E C, Schenkel F S, Quinton V M, Friendship R M and Robinson J A B. 2013. Meat-analysis of genetic parameter estimates for reproduction, growth and carcass traits of pigs in the tropics. *Livestock Science* **152**: 101–13.

Arango J, Misztal I, Tsuruta S, Culbertson M, Holl J W and Herring W. 2006. Genetic study on individual pre-weaning mortality and birth weight in Large White piglets using threshold models. *Livestock Science* **101**: 208–18.

Banville M, Riquet J, Bahon D, Sourdioux M and Canario L. 2015. Genetic parameters for litter size, piglet growth and sow's early growth and body composition in the Chinese-European line Tai Zumu. *Journal of Animal Breeding and*

Genetics **132**: 328–37.

Cauveri D, Sivakumar T and Devendran P. 2009. Pre-weaning body weights in Large White Yorkshir crosses. *Indian Journal of Animal Research* **43**(2): 130–32.

Chansomboon C, Elzo M A, Suwanasopee T and Koonawootrittriron S. 2010. Estimation of genetic parameters and trends for weaning-to-first service interval and litter traits in a commercial Landrace-Large White Swine population in Northern Thailand. *Asian Australasian Journal of Animal Science* **23**(5): 543–55.

Chimonyo M, Dzama K and Bhebhe E. 2006. Genetic determination of individual birth weight, litter weight and litter size in Mukota pigs. *Livestock Science* **105**: 69–77.

Chimonyo M and Dzama K. 2007. Estimation of genetic parameters for growth performance traits in Mukota pigs. *Animal* **2**: 317–23.

Das D, Deka D, Nath D R and Goswami R N. 2005. Estimates of heritability and effects of some nongenetic factors on traits of reproduction in Hampshire pig. *Indian Veterinary Journal* **82**: 847–50.

Devi V M and Jayashankar M R. 2014. Effect of inbreeding on the litter traits of Large White Yorkshire sows. *Indian Journal of Veterinary and Animal Sciences Research* **43**(4): 316–22.

Dube B, Sendros D, Mulugeta D and Dzama K. 2012. Estimation of genetic and phenotypic parameters for sow productivity traits in South African large white pigs. *South African Journal of Animal Science* **424**: 389–97.

Dufranse M, Misztal I, Tsuruta S, Holl J, Gray K A and Gengler N. 2014. Estimation of genetic parameters for birth weight, pre-weaning mortality and hot carcass weight of crossbred pigs. *Indian Journal of Animal Sciences* **91**: 5565–71.

Ehlers M J, Harry J W, Bertrand J K and Stalder K J. 2005. Variance components and heritabilities for sow productivity traits estimated from purebred versus crossbred sows. *Journal of Animal Breeding and Genetics* **122**: 318–24.

Fernandez A, Rodriganez J, Zuzuarregui J, Rodriguez M C and Silio L. 2008. Genetic parameters for litter size and weight at different parities in Iberian pigs. *Spanish Journal of Agriculture Research* **6**: 1–9.

Ganesan R, Dhanavanthan P, Kiruthika P, Kumarasamy P, Murugan M and Jaishankar S. 2013. Factors influencing growth performance and estimation of genetic parameters in crossbred pigs. *Journal of Agriculture and Veterinary Science* **56**: 63–71.

Gopinathan A and Usha A P. 2011. Comparative evaluation of growth and carcass traits in Large White Yorkshire, Desi and their crossbred pigs. *Indian Journal of Animal Research* **453**: 203–06.

Gowrimanokari K V, Thiagarajan R, Venkataramanan R and Gopi. 2018. Effect of inbreeding on pre-weaning and sow performance traits in Large White Yorkshire pigs. *Indian Journal of Animal Research*. DOI: 10.18805/ijar.B-3623

Grandinson K, Lund M S, Rydhmer L and Strandberg E. 2002. Genetic parameters for the piglet mortality traits crushing, stillbirth and total mortality and their relation to birth weight. *Indian Journal of Animal Sciences* **52**: 167–73.

Henderson C R. 1975. Best linear unbiased estimation and prediction under a selection model. *Biometrics* **31**: 423–47.

Hermesch S, Luxford B G and Graser H U. 2001. Estimation of variance components for individual piglets weight at birth and 14 days of age. *Proceedings for Association of Advancement of Animal Breeding and Genetics* **14**: 207–10.

Ilatsia E D, Githinji M G, MuasyaT K, Okeno T O and Kahi A K. 2008. Genetic parameter estimates for growth traits of Large White pigs at Kenya. *South African Journal of Animal Science* **383**: 166–73.

Imboonta N, Rydhmer L and Tumwasorn S. 2007. Genetic parameters for reproduction and production traits of Landrace sows in Thailand. *Journal of Animal Science* **85**: 53–59.

Jayarajan S. 1985. 'Genetic studies on Large White Yorkshire pigs in livestock research station, Kattupakkam'. PhD Thesis, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu.

Kalitha D, Goswami R N and Deka D. 2006. Genetic studies on body weight of crossbred pigs of Assam. *Indian Veterinary Journal* **83**: 850–52.

Kaufmann D, A Hofer, Bidanel J P and Kunzi N. 2000. Genetic parameters for individual birth and weaning weight and for litter size of Large White pigs. *Journal of Animal Breeding and Genetics* **117**(3): 121–28.

Kaushik P, Handique P J, Rahman H, Das A, Das A K and Bhuyan G. 2013. Pre-weaning growth performance of pure and crossbred pigs under organized farm condition in Assam. *International Journal of Engineering Science Invention* **2**(6): 10–12.

Kiszlinger H N, Farkas J, Kover G, Nguyen N T and Nagy I. 2015. Genetic parameters and breeding value stability estimated from a joint evaluation of purebred and crossbred sows for litter weight at weaning. *Acta Agraria Kaposvariensis* **19**(1): 1–7.

Kumari P B and Sreenivasa Rao D. 2010. Factors influencing pre and post weaning growth rates in Large White Yorkshire × indigenous pigs. *Indian Veterinary Journal* **87**: 614–15.

Lund M S, Puonti M, Rydhmer L and Jensen J. 2002. Relationship between litter size and perinatal and pre-weaning survival in pigs. *Indian Journal of Animal Sciences* **74**: 217–12.

Meyer K. 1992. Variance components due to direct and maternal effects for growth traits of Australian beef cattle. *Livestock Production Science* **31**: 179–204.

Meyer K. 2007. WOMBAT A tool for mixed model analyses in quantitative genetics by REML. *Journal of Zhejiang University Science* **811**: 815–21.

Mondal S K and Kumar A. 2015. Genetic evaluation of pre-weaning growth traits in Landrace × Desi piglets. *Indian Journal of Animal Research* **492**: 273–75.

Norris D, Varona L, Visser D P, Theron H E, Voordewind S F and Nesamvuni E A. 2006. Estimation of the additive and dominance variances in South African Landrace pigs. *South African Journal of Animal Science* **36**: 261–68.

Paura L, Jonkus D and Permanickis U. 2014. Genetic parameters and genetic gain for reproduction traits in Latvian landrace and Yorkshire sows populations. *Animal and Veterinary Sciences* **2**(6): 184–88.

Phookan A, Laskar S, Aziz A and Goswami R N. 2006. Reproductive performance of indigenous pigs of the Brahmaputra valley of Assam. *Tamil Nadu Journal of Veterinary and Animal Sciences* **2**(4): 121–25.

Prakash G M, Ravi A, Punya Kumari B and Srinivasa Rao D. 2008. Reproductive and productive performance of crossbred pigs. *Indian Journal of Animal Sciences* **7811**: 1291–97.

Rokde N K, Thakur M S, Parmer S N S and Tomar S S. 2013. Effect of various genetic and non-genetic factors on reproductive traits in Large White Yorkshire crossbred and Tamworth crossbred pigs. *Journal of Animal Research* **32**: 173–78.

Wright S. 1931. Correlation and causation. *Journal of Agricultural Research* **20**(7): 557–85.