HERITABILITY AND REPEATABILITY ESTIMATES OF MATERNAL PERFORMANCE TRAITS IN PUREBRED AND CROSSBRED DOES

LUKEFAHR S.D.*, HAMILTON H.H.**

* Department of Animal & Wildlife Sciences, Texas A&M University, KINGSVILLE, TX 78363, USA.
** Zootechnician, UNDP, Poste Restante, 34551, LIPIK, Croatia.

ABSTRACT : Data on purebred doe (298 litters) and combined purebred and crossbred doe (461 litters) production records were collected over a 2-year period (1990 and 1991) and analyzed separately to obtain heritability and repeatability estimates. Doe breed types were Californian (CAL), New Zealand White (NZW) and CAL x NZW. Litters were sired by bucks representing four breeds or lines - CAL, NZW, and control and selected synthetics. Maternal performance traits included doe body weight at parturition, gestation length, litter size and weight at birth, 21 d, and weaning (28 d), doe production efficiency (litter weaning weight/doe body weight), 1-21 d and 1-28 d total doe and litter feed intake, and neonatal and preweaning survival rates. A doe repeatability model was employed which consisted of fixed effects of year, season, parity, and doe breed type, and random direct additive genetic, permanent and residual effects. Sire breed and individual service sire of the litter were added to this model for the analysis of litter weaning weight. Heritability and repeatability estimates were reasonably similar for all traits studied between pooled purebred and combined purebred and crossbred data analyses. From pooled purebred doe data analysis, heritability (repeatability) estimates for doe body weight, gestation length, and litter size at birth, 21 d, and 28 d were 0.53, 0.00, 0.13, 0.00, and 0.00 (0.72, 0.09, 0.23, 0.06, and 0.06), respectively. For doe production efficiency and litter weights at birth, 21 d and 28 d, heritabilities (repeatabilities) were 0.07, 0.14, 0.09, and 0.03 (0.07, 0.14, 0.09, and 0.03); however, when statistically adjusted for the corresponding litter size, heritabilities (repeatabilities) changed to 0.06, 0.00, 0.02, and 0.00 (0.06, 0.24, 0.30, and 0.28), respectively. Heritabilities (repeatabilities) of 0.13 and 0.13 (0.30 and 0.21) were obtained for 1-21 d and 1-28 d total doe and litter feed intake. Lastly, neonatal and preweaning survival rates had heritability (repeatability) estimates of 0.13 and 0.00 (0.16 and 0.19). In summary, maternal performance traits tend to be lowly heritable (except for doe body weight) and lowly to moderately repeatable.

RESUME : Estimation de l'héritabilité et de la répétabilité des performances maternelles des lapines de race pure et croisées. Les performances de 298 portées en souche pure et de 461 portées soit croisées soit de souche pure sont enregistrées pendant 2 ans (1990-1991) L'héritabilité et la répétabilité sont estimées dans chaque échantillon. Les races utilisées sont : Californien (CAL), Néo-zélandais blanc (NZW) et CAL x NZW. Les portées sont issus de mâles représentant quatre lignées : CAL, NZW, un témoin, et des mâles d'une souche synthétique. Les caractéristiques maternelles enregistrées ont été : le poids vif à la mise bas, la durée de gestation, la taille de la portée et son poids à la naissance, à 21 jours, au sevrage (28 jours), l'efficacité de production (poids de la portée au sevrage/poids vif de la lapine), la consommation totale de la mère et de sa portée jusqu'au 21eme ou au 28eme jour post partum et le taux de mortalité périnatale et jusqu'au sevrage. Le modèle de répétabilité concernant les lapines comprend les effets fixes de l'année, de la saison, de la parité, la race de la lapine, et en effets alléatoires, la valeur génétique additive, le milieu permanent et la résiduelle. La race et les caractéristiques individuelles du mâle géniteur d'une portée ont été ajouté au modèle pour analyser le poids de la portée au sevrage. Les estimées de l'héritabilité et de la répétabilité ont été presque identiques pour toutes les caractéristiques étudiées que l'on considère les races pures ou les races pures combinées aux croisés. L'analyse des résultats concernant l'ensemble des lapines de races pures donne une estimation de l'héritabilité et de la répétabilité pour le poids vif de la lapine, la durée de gestation, le poids de la portée à la naissance, 21 jours et 28 jours de 0,53 ; 0,00 ; 0,13 ; 0,00 ; 0,00 et 0,72 ; 0,09 ; 0,23 ; 0,06 ; 0,06, respectivement. Pour l'efficacité de production de la lapine, les poids de la portée à la naissance, aux ages de 21 et de 28 jours, l'héritabilité et la (répétabilité) sont de 0,07 ; 0,14 ; ;0,09 ;0,03 et (0,07 ; 0,14 ; 0,09 ; 0,03) ; en outre, lorsqu'elles sont statistiquement ajustées à la taille de la portée correspondantes, les héritabilitiés et les (répétabilités) deviennent : 0,06 ; 0,00 ; 0,02 ; 0,00 et (0,06 ; 0,24 ; 0,30 ; 0,28), respectivement. Des héritabilités et des (répétabilités) de 0,13 ; 0,13 et (0,30 ; 0,21) ont été obtenus pour les consommations totales de la mère et de sa portée jusqu'à 1/21 et 1/28 jours post partum, respectivement. Enfin l'héritabilité et la (répétabiliité) des taux de mortalité néonatale et au sevrage sont estimées à 0,13 et 0,00 et (0,16 et 0,19). En résumé, les caractéristiques des performances maternelles semblent faiblement héritables (excepté pour le poids vif) et de faiblement à modérement répètable.

INTRODUCTION

AFIFI et al. (1989) proposed that preweaning litter traits should be considered as female traits for herd improvement through selection and/or culling strategies. The view that major paternal effects (excluding sire breed differences) on litter traits may largely be absent is generally supported by the rabbit literature. Moreover, preweaning litter traits tend to be closely connected to the size of the litter (e.g., gestation length, litter weights and kit survival), which is primarily a trait of the female based on ovulation rate (HULOT and MATHERON, 1979; BLASCO et al., 1993).

Review papers by KHALIL et al. (1986) and by ROCHAMBEAU (1988) verify that heritability and/or repeatability estimates for preweaning traits have a broad range among reports. Reasons may include real genetic differences among populations, random variation, environmental dissimilarities, and methods of estimation (e.g., paternal half-sib versus full animal model), etc. Further studies are needed to provide a consensus among literature reports. Our objectives were to estimate heritability and repeatability for several maternal performance traits (as criteria for selection or culling programs) based on records from pooled purebred doe data or from combined purebred and crossbred doe data.

MATERIALS AND METHODS

Experimental population

Data on preweaning maternal and postweaning performance traits were collected over two years (1990

Table 1: Descriptive statistics for maternal performance traits[a]

Trait[b]	Statistic			
	Mean	SD	Range, minimum	Range, maximum
DBW, g	4263	481	2716	5642
GL, d	31.6	0.88	27	34
TLSB	9.0	2.75	1	15
LS21	7.2	2.54	1	13
LSW	7.0	2.52	1	12
LBW, g	502	134	86	855
L21W, g	2347	698	228	4120
LWW, g	3643	1203	289	6735
DPE	0.86	0.29	0.08	1.77
1-21FI, g	7335	1778	2500	12202
1-28FI, g	10769	2620	3190	17530
NSR, %	93.0	13.65	17	100
PSR, %	85.8	18.11	11	100

[a]Sample size was 461 litters from 175 purebred and crossbred does. Data were collected over a 2-year period (except feed intake data was collected in the first year of the experiment; n = 250 litters).

[b]Trait abbreviations: DBW = doe body weight at parturition; GL = gestation length; TLSB = total litter size born; LS21 = litter size at 21 d; LSW = litter size at weaning (28 d); LBW = litter birth weight; L21W = litter weight at 21 d; LWW = litter weight at weaning; DPE = doe production efficiency (LWW/DBW); 1-21FI = cumulative doe feed intake from 1 to 21 d; 1-28FI = cumulative doe and litter feed intake from 1 to 28 d; NSR = neonatal survival rate; PSR = preweaning survival rate.

and 1991) at Alabama A&M University. Doe breed types included 59 Californian (CAL) and 56 New Zealand White (NZW) purebreds, and 60 CAL sire x NZW crossbreds. Service sires (162 bucks) representing NZW and CAL, and control and select synthetic lines were used. Control synthetic bucks were from a randomly selected line, whereas select synthetic bucks were from a line that was phenotypically selected for increased 70-d body weight (LUKEFAHR et al., 1996b). Approximately ten different bucks from each of the four sire lines were used in each of four, 6-mo breeding cycles. Paternal breed effects, presumed to be of lesser importance on preweaning traits, on postweaning fryer and litter trait performances were previously reported by KHAN and LUKEFAHR (1996).

Breeding management

A 14-d breeding schedule was practiced, which allows for a doe to produce a maximum of 8 litters per annum. Each doe was randomly assigned to one of the four sire lines (throughout the experiment as cages were vacated) for the duration of one full year of production. For each mating, a doe was randomly assigned a buck within that sire line so as to prevent a potential individual doe by sire line interaction effect. Repeat matings to the same buck, or closely related matings (based on pedigree information) were avoided.

Does were palpated for pregnancy 14 d after service. If not pregnant, the doe was immediately rebred to another buck of the designated sire line. On d 28 of gestation, a wooden nest box (40 x 20 x 20 cm) was placed in the doe's cage. No cross-fostering of kits among does was practiced so that a doe's own producing ability could be assessed.

Does were culled for poor health and for infertility (i.e., failure to wean at least one kit after three consecutive matings). When a doe died or was culled, a replacement doe from any of the three doe breed types was randomly assigned to the cage, and the designated service sire line was re-randomized. The experiment was initiated with nulliparous (first mated at 5 mo of age) and multiparous does. To keep parity classes (1st through 8th) somewhat balanced, does were removed after one full year of production. Maternal breed preweaning performance results have been reported by Hamilton and Lukefahr (1997).

Traits studied

Doe body weight at parturition (g), gestation length (d), litter size and weight (g) at birth, 21 d, and weaning (28 d), doe production efficiency (litter weaning weight divided by doe body weight), and neonatal and preweaning survival rates (%) were measured. Litters which did not survive to weaning (<5%) were eliminated from the data set. In addition, total doe and litter feed intake (1 to 21 d and 1 to 28 d, g) were recorded in the first year of the experiment. Descriptive statistics for all traits studied based on purebred and crossbred doe performance are presented in Table 1.

Statistical procedures

In preliminary analyses of all traits, heritability and repeatability estimates were computed separately based on: 1) pooled purebred data (n = 298 litter records from 113 does), and 2) combined purebred and crossbred data (n = 461 litter records from 175 does). In the pooled purebred data set, the genetic relationship matrix (A) involved 177 animals (113 does with records plus 64 purebred base animals which contributed to doe pedigree data). In the combined data set, the genetic relationship matrix (A) involved 259 animals (175 purebred and crossbred does with records plus 84 purebred base animals which contributed to doe pedigree data).

The AIREML (Average Information Restricted Maximum Likelihood) animal model procedure by Johnson and Thompson (1995) was employed to estimate variance components from analyses of both data sets. A doe repeatability model consisted of fixed effects of year, season of year, parity (classes: 1 = first,

2 = second through fifth, and 3 = sixth through eighth parities), and doe breed type. Random sources included additive genetic ~$(0, A\sigma^2_a)$, non-additive plus permanent environmental ~$(0, I\sigma^2_p)$, and temporary environmental (residual) effects ~$(0, I\sigma^2_e)$.

In the purebred data analysis, genetic variance was assumed to be homogeneous for all traits for CAL and NZW breeds. Our rationale was justified on the basis that both breeds share some common ancestry, and have a production trait selection history in the U.S. For the purpose of heritability and repeatability estimation, the homogeneous variance assumption has also been implied by KHALIL et al. (1988), AFIFI et al. (1989) and KROGMEIER et al. (1994). Moreover, GARCIA et al. (1982) in Spain and FERRAZ et al. (1992) in Brazil reported similar heritabilities for doe and litter production traits that were estimated separately for CAL and NZW.

Heritability was expressed as the ratio of additive genetic variance (σ^2_a) to total phenotypic variance $(\sigma^2_t = \sigma^2_a + \sigma^2_p + \sigma^2_e)$. A second estimate of heritability was obtained for gestation length, litter weights and doe production efficiency using litter size at the corresponding age as a linear covariate source. For the analysis of litter weaning weight, the fixed sire line and random service sire of the litter (nested within line) ~$(0, I\sigma^2_s)$ effects were added to the model described above, based on previous results which suggested important paternal effects on only individual 28-d weaning weight (KHAN and LUKEFAHR, 1996). For comparison purposes, heritabilities were computed for neonatal and preweaning survival rates before and after being subjected to arc-sin transformation. This transformation was done prior to analyses to minimimize possible scaling effects between corresponding survival rate and variance values. Repeatability was expressed as the ratio of variances by summing additive genetic and permanent effects $(\sigma^2_a + \sigma^2_p)$ to total phenotypic variance (σ^2_t). Standard errors were computed for ratios of σ^2_a and σ^2_p to σ^2_t from AIREML analyses, but not for repeatability because the latter was not directly computed.

RESULTS AND DISCUSSION

Heritability estimates for maternal performance traits

Ratios of variances due to additive genetic, permanent and residual effects were similar for all traits investigated when comparing analyses between pooled purebred versus combined purebred and crossbred data. Therefore, only the pooled purebred data analysis results will be presented and discussed in detail (Table 2). Results from the combined purebred and crossbred data analysis are shown in Table 3.

Table 2: Estimates of heritability, permanent effects, and repeatability for maternal performance traits from pooled purebred data

| Trait | Statistic[a] | | |
	h^2	p^2	R
Doe body weight, g	0.53 ± 0.20*	0.19 ± 0.18	0.72
Gestation length, d	0.00 ± 0.13	0.09 ± 0.12	0.09
Gestation length, d[b]	0.00 ± 0.13	0.09 ± 0.13	0.09
Total litter size born	0.13 ± 0.13	0.10 ± 0.12	0.23
Litter size at 21 d	0.00 ± 0.08	0.06 ± 0.10	0.06
Litter size weaned (28 d)	0.00 ± 0.08	0.06 ± 0.10	0.06
Litter birth weight, g	0.14 ± 0.11	0.01 ± 0.10	0.14
Litter birth weight, g[b]	0.00 ± 0.13	0.24 ± 0.14	0.24
Litter weight at 21 d, g	0.09 ± 0.11	0.00 ± 0.11	0.09
Litter weight at 21 d, g[b]	0.02 ± 0.11	0.29 ± 0.13*	0.30
Litter weaning weight, g	0.03 ± 0.09	0.00 ± 0.10	0.03
Litter weaning weight, g[b]	0.00 ± 0.11	0.28 ± 0.13*	0.28
Doe production efficiency	0.07 ± 0.07	0.00 ± 0.09	0.07
Doe production efficiency[b]	0.06 ± 0.09	0.00 ± 0.10	0.06
Feed intake (1 to 21 d), g	0.13 ± 0.21	0.18 ± 0.21	0.30
Feed intake (1 to 28 d), g	0.13 ± 0.20	0.09 ± 0.20	0.21
Neonatal survival rate, %	0.13 ± 0.12	0.03 ± 0.12	0.16
Neonatal survival rate, %[c]	0.16 ± 0.12	0.03 ± 0.12	0.19
Preweaning survival rate, %	0.00 ± 0.11	0.19 ± 0.12	0.19
Preweaning survival rate, %[c]	0.00 ± 0.11	0.20 ± 0.12	0.20

[a]Symbols: h^2 = heritability (additive genetic variance as a proportion of phenotypic variance) ; p^2 = permanent effects (presumed non-additive genetic plus permanent environmental effects variance as a proportion of phenotypic variance); R = repeatability (sum of h^2 and p^2),

[b]Adjusted for the linear covariate of litter size at the corresponding age. Also, the random effect of service sire (s) within sire breed or line was included in the same covariate analysis of litter weaning weight (σ^2_s= 0.06 ± 0.06).

[c]NSR and PSR normalized by arc-sin transformation ; $P < 0.05$.

Heritability estimates for maternal traits tended to be low in magnitude ($h^2 \leq 0.16$), except for doe body weight at parturition which was highly heritable ($h^2 = 0.53$). However, heritabilities may have been higher if standardization for litter size following birth had been practiced. Heritability estimates of zero were obtained for gestation length, adjusted or not adjusted for total litter size at birth. FERRAZ et al. (1992) reported a low heritability of 0.06 for gestation length, although KHALIL et al. (1988) reported a much higher estimate of 0.45. Heritability of total litter size born was 0.13. Low heritability estimates for litter size born ranging from 0.02 to 0.07 were also obtained by ROLLINS et al., (1963), JOHNSON et al. (1988), BASELGA et al. (1992), FERRAZ et al. (1992) and PANELLA et al. (1992). However, other studies (MGHENI and CHRISTENSEN, 1985; KHALIL et al., 1987, 1988; KROGMEIER et al., 1994; AYYAT et al., 1995) reported heritability values ≥ 0.20, but not being significantly different from zero because of high

Table 3: Estimates of heritability, permanent effects, and repeatability for maternal performance traits from combined purebred and crossbred data

Trait	Statistic[a] h^2	p^2	R
Doe body weight, g	0.62 ± 0.16**	0.07 ± 0.13	0.69
Gestation length, d	0.00 ± 0.07	0.09 ± 0.07	0.09
Gestation length, d[b]	0.00 ± 0.08	0.09 ± 0.08	0.09
Total litter size born	0.13 ± 0.09	0.08 ± 0.09	0.21
Litter size at 21 d	0.04 ± 0.07	0.04 ± 0.08	0.08
Litter size weaned (28 d)	0.06 ± 0.07	0.01 ± 0.08	0.07
Litter birth weight, g	0.15 ± 0.10	0.04 ± 0.09	0.19
Litter birth weight, g[b]	0.00 ± 0.09	0.24 ± 0.10*	0.24
Litter weight at 21 d, g	0.09 ± 0.08	0.00 ± 0.08	0.09
Litter weight at 21 d, g[b]	0.06 ± 0.08	0.20 ± 0.10*	0.27
Litter weaning weight, g	0.05 ± 0.07	0.02 ± 0.07	0.07
Litter weaning weight, g[b]	0.03 ± 0.09	0.27 ± 0.10*	0.31
Doe production efficiency	0.07 ± 0.07	0.00 ± 0.08	0.07
Doe production efficiency[b]	0.03 ± 0.06	0.04 ± 0.07	0.08
Feed intake (1 to 21 d), g	0.12 ± 0.14	0.12 ± 0.15	0.23
Feed intake (1 to 28 d), g	0.11 ± 0.14	0.07 ± 0.14	0.18
Neonatal survival rate, %	0.08 ± 0.08	0.04 ± 0.08	0.12
Neonatal survival rate, %[c]	0.06 ± 0.08	0.06 ± 0.08	0.13
Preweaning survival rate, %	0.00 ± 0.07	0.10 ± 0.08	0.10
Preweaning survival rate, %[c]	0.00 ± 0.06	0.12 ± 0.08	0.12

[a]Symbols: h^2 = heritability (additive genetic variance as a proportion of phenotypic variance); p^2 = permanent effects (presumed non-additive genetic plus permanent environmental effects variance as a proportion of phenotypic variance); R = repeatability (sum of h^2 and p^2).

[b]Adjusted for the linear covariate of litter size at the corresponding age. Also, the random effect of service sire (s) within sire breed or line was included in the same covariate analysis of litter weaning weight (σ^2_s = 0.05 ± 0.04).

[c]NSR and PSR normalized by arc-sin transformation ; $P < 0.05$; **$P < 0.01$.

standard errors. The present heritability estimate of 0.00 for litter size at 21 d is within the range of estimates of 0.11, 0.13, and 0.00 by RANDI and SCOSSIROLI (1980), AYYAT et al. (1995) and LUKEFAHR et al. (1996a), respectively. A heritability estimate of 0.00 was also observed for litter size at weaning. Heritabilities ranging from 0.02 to 0.52 involving several different methods of analysis have been documented from experiments and/or review papers (BASELGA et al., 1982, 1992; JOHNSON et al., 1988; KHALIL et al., 1988; MOURA et al., 1991; FERRAZ et al., 1992; PANELLA et al., 1992; KROGMEIER et al., 1994; POUJARDIEU et al., 1994; ROCHAMBEAU et al., 1994; AYYAT et al., 1995).

Heritability of litter birth weight was estimated at 0.14. LAMPO and VAN DEN BROECK (1975), KROGMEIER et al. (1994) and AYYAT et al. (1995) obtained similar estimates of 0.11, 0.13 and 0.10, respectively. The heritability of 0.09 for litter weight at 21 d corresponds with estimates of 0.01 by LUKEFAHR et al. (1996a) and 0.11 by RANDI and SCOSSIROLI (1980). A heritability of 0.03 was observed for litter

weaning weight. A broad range of heritability estimates (0.04 to 0.57) for litter weaning weight has been reported (GARCIA et al., 1980; KHALIL et al., 1987; JOHNSON et al., 1988; MOURA et al., 1991; FERRAZ et al., 1992; PANELLA et al., 1992; KROGMEIER et al., 1994; AYYAT et al. 1995). Surprisingly, adjustment for litter size resulted in a decrease in heritability estimates for all three litter weight traits. LUKEFAHR et al. (1996a) reported an increase in heritability from 0.01 to 0.10 for litter weight at 21 d when an adjustment was made for litter size at 21 d, which is higher than the present estimate of 0.02.

Heritability of doe production efficiency was low at 0.07. Adjustment of the character for litter size weaned only slightly changed the estimate to 0.06. Feed intakes from 1 to 21 d (doe) and from 1 to 28 d (doe and litter) had the same heritability value of 0.13. LAMPO and VAN DEN BROECK (1975) reported a similar heritability of 0.15 for a preweaning feed index trait. Heritability estimates for neonatal and preweaning survival rates were 0.13 and 0.00 before, and 0.16 and 0.00 after, arc-sin transformation, indicating little effect due to the transformation. JOHNSON et al. (1988) reported a similar heritability of 0.11 for neonatal survival rate. Also consistent with present estimates, LAMPO and VAN DEN BROECK (1975), JOHNSON et al. (1988), FERRAZ et al. (1992), and KROGMEIER et al. (1994) reported heritabilities of 0.02, 0.08, 0.00, and 0.00 for preweaning survival rate. KHALIL et al. (1988) obtained a heritability of 0.15 for rate of preweaning mortality.

According to BLASCO et al. (1993), heritability of litter size in rabbits is low ($h^2 \sim 0.1$). In France, efforts to increase litter size through genetic selection have not been promising (POUJARDIEU et al., 1994; ROCHAMBEAU et al., 1994), despite the rather large heritability estimates reported from other investigations. Because phenotypic variation in other preweaning traits generally includes a major component due to litter size, it is not surprising that low heritability estimates for other such traits are reported. However, recent work by BLASCO et al. (1993) reporting moderate estimates of heritability ($0.2 < h^2 < 0.3$) for the components of litter size (i.e., ovulation rate and number of embryos) is encouraging. Another useful experiment would involve estimation of heritability for milk production or litter growth following actual standardization for litter size at birth.

Repeatability estimates for maternal performance traits

Repeatability estimates for maternal traits tended to be low to moderate in magnitude (range between 0.03 and 0.30, Table 2), except for doe body weight at parturition which was highly repeatable (0.72), primarly because it was highly heritable. LUKEFAHR et

al. (1983b) previously reported the same repeatability value for this trait. Repeatabilities for gestation length, unadjusted and adjusted for litter size born, were the same (0.09). A repeatability value of 0.15 was calculated from the results of FERRAZ et al. (1992). KHALIL et al. (1988) reported lower repeatability (0.17) than heritability (0.45) for this trait, which questions the reliability of their results. AFIFI et al. (1989) reported that only 1% of total variation in gestation length was attributable to the doe.

Repeatability of total litter size born was 0.23. This estimate is within the range of 0.05 to 0.26 reported in the literature (ROUVIER et al., 1973; SUH et al., 1978; GARCIA et al., 1982; LUKEFAHR et al., 1983a, 1984; LAHIRI, 1984; KHALIL et al., 1988; KHALIL, 1994; AYYAT et al., 1995). A repeatability estimate of 0.06 was observed for litter size at 21 d. ROUVIER et al. (1973), LUKEFAHR et al. (1983b) and AYYAT et al. (1995) reported higher repeatabilities for the same trait of 0.13, 0.23, and 0.15, respectively. Repeatability of 0.06 was also obtained for litter size at weaning. This estimate is within the reported range of 0.02 to 0.23 (DONAL, 1973; SUH et al., 1978; GARCIA et al., 1982; LUKEFAHR et al., 1983a, 1984; LAHIRI, 1984; KHALIL et al., 1988; MOURA et al., 1991; KHALIL, 1994; Ayyat et al., 1995).

Repeatability of litter birth weight was estimated at 0.14. For the same trait, LUKEFAHR et al. (1983a, 1984), LAHIRI (1984), KHALIL (1994), and AYYAT et al. (1995) reported repeatability estimates of 0.33, 0.09, 0.30, 0.05, and 0.21, respectively. A repeatability estimate of 0.09 was obtained for litter weight at 21 d. ROUVIER et al. (1973), LUKEFAHR et al. (1983b, 1984), KHALIL (1994), and LUKEFAHR et al. (1996a) estimated repeatabilities for the same trait, ranging from -0.03 to 0.25. For litter weaning weight, repeatability was estimated at 0.03. According to the literature (GARCIA et al., 1982; LUKEFAHR et al., 1983a, 1984; LAHIRI, 1984; MOURA et al., 1991; FERRAZ et al., 1992; KHALIL, 1994; AYYAT et al., 1995), repeatability estimates for litter weaning weight range from 0.07 to 0.22. When adjusted for litter size, repeatabilities for litter weights at birth, 21 d, and weaning consistently increased to 0.24, 0.30, and 0.28, respectively. LUKEFAHR et al. (1984) likewise observed an increase in the repeatability estimate for average weaning weight per kit when statistically adjusted for litter size (0.07 to 0.41).

Repeatability and heritability estimates for doe production efficiency were the same (0.07 and 0.06), suggesting the absence of non-additive genetic and permanent environmental effects. However, these permanent sources of variation were important for doe body weight and also for litter weaning weight (adjusted for litter size). For feed intake from 1 to 21 d (doe) and from 1 to 28 d (doe and litter), repeatabilities of 0.30 and 0.21 were obtained. For 1 to 21 d feed intake, LUKEFAHR et al. (1983b, 1984) reported repeatabilities of 0.27 and 0.58, whereas for 1 to 28 d feed intake, LUKEFAHR et al. (1983a, 1984) reported

repeatabilities of 0.19 and 0.28. Repeatabilities for neonatal and preweaning survival rates of 0.16 and 0.19 were obtained before, and 0.19 and 0.20 after, data transformations, respectively. LUKEFAHR et al. (1983a) estimated repeatability to be 0.16 for neonatal survival rate. Repeatabilities of 0.05 and 0.21 for neonatal survival rate from NZW and Fauve de Bourgogne purebred doe populations were reported by ROUVIER et al. (1973). LAMPO and VAN DEN BROECK (1975) and LUKEFAHR et al. (1983a, 1984) reported repeatabilities of 0.12, 0.22, and 0.18, respectively, for preweaning survival rate. For preweaning mortality rate, KHALIL et al. (1988) and FERRAZ et al. (1992) obtained repeatabilities of 0.00 and 0.10.

KROGMEIER et al. (1994) reported that maternal (genetic and environmental) effects for preweaning traits may account for as much as 14% of total phenotypic variation. Although the maternal genetic variance was not partitioned in our model, this source should have been contained in the permanent effects variance, and thus be reflected in our estimates of repeatability. In general, since estimates of repeatability were numerically greater than those of heritability, other permanent contributions (e.g., maternal additive and non-additive genetic, direct non-additive genetic, epistatic, and environmental effects) to doe production besides direct additive genetic effects are suggested.

Litter weaning weight is an economically important composite trait of the doe. This is because litter weaning weight is affected by litter size and kit viability, mothering and milking ability, and growth response of the litter. Based on the repeatability estimate of 0.28 for litter weaning weight (adjusted for litter size weaned), this trait could potentially be used as a culling criterion to improve doe herd productivity in terms of litter mass production.

Combined purebred and crossbred data analysis

An advantage of the combined analysis was genetic relationships between purebred and crossbred does, parents and/or "base animals" as ancestors were taken into account through pedigree information, as well as utilization of all available records. For example, several purebred CAL bucks sired both purebred and crossbred daughters. Also, several purebred NZW does involved in the study contributed crossbred replacements and/or were related as full- or half-sibs to other purebred and crossbred does. Previous studies involving cattle have demonstrated that the inclusion of purebred and crossbred data should enhance genetic ties in a population (VAN RADEN, 1992), improve accuracy of genetic merit prediction (ARMSTRONG et al., 1994), and also allow for the evaluation and comparison of animal genetic merit within and across purebred and crossbred animal groups (ARNOLD et al., 1992; NUNEZ-DOMINGUEZ et al., 1993). However, genetic variance in crossbred groups may be different from that of purebreds, for example, being affected by dominance and disequilibrium; hence, the reason for

comparing separate results from pooled purebred versus combined purebred and crossbred data analyses. In this comparison, heritability and repeatability estimates were similar for most traits investigated. However, further studies involving larger data sets that would yield more precise heritability and repeatability estimates are warranted.

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