Anim. Prod. 1987, **45:** 123-134
0003-3561/87/69070123$02·00

A GENETIC ANALYSIS OF LITTER TRAITS IN BAUSCAT AND GIZA WHITE RABBITS

M. H. KHALIL
Department of Animal Production, Faculty of Agriculture at Moshtohor, Zagazig University, Banha Branch, Egypt

J. B. OWEN
Department of Agriculture, University College of North Wales, Bangor, Gwynedd LL57 2UW

AND

E. A. AFIFI
Department of Animal Production, Faculty of Agriculture at Moshtohor, Zagazig University, Banha Branch, Egypt

ABSTRACT

An analysis of doe productivity traits was carried out on 884 litter records including 52 sires and 210 daughters (paternal half sisters) of Bauscat (B) and Giza White (G) rabbits. Traits examined included litter size and weight at birth and at weaning, pre-weaning mortality and mean weight of young at weaning. Year-of-kindling affected most litter traits but no pattern of parity effects on litter size and pre-weaning mortality was observed. Litter weight and mean weight of young at weaning generally increased linearly as parity advanced. Litter size and weight and mean weight of young tended to increase as month of kindling advanced from October to March, and to decrease again during April and May. Pre-weaning mortality decreased as month of kindling advanced up to March and increased thereafter during April and May. The sire of the doe affected all litter traits studied, with the exception of litter size at birth and pre-weaning mortality in the B breed. Estimates of heritability for most of the litter traits were moderate or high. Genetic and phenotypic correlations among litter size traits and between litter size and litter weight traits were positive and relatively moderate or large. Litter weight traits were positively correlated both genetically and phenotypically. The genetic and phenotypic correlations between litter size traits and mean weight of young at weaning were negative and relatively moderate or large.

INTRODUCTION

THE ability of a doe to produce thrifty young at birth, referred to as prolificacy, and to raise these young to weaning, referred to as maternal or nursing ability, are the main characters determining her productivity. Litter size and weight at weaning are usually regarded as the best estimates of number and weight of young produced by the doe since they are a function of all pre-weaning effects. Therefore, the larger the number of young the doe kindles and weans, the greater the crop would be.

Researchers generally recognize that the genetic evaluation of doe productivity can be improved by the statistical adjustment of productivity for significant management and environmental influences. Evidence in the literature (Afifi, Galal, El-Tawil and El-Khishin, 1976a; Lukefahr, Hohenboken, Cheeke and Patton, 1983) indicates that year of kindling, parity and month of kindling are the most important environmental factors affecting litter traits in rabbits. There are a few estimates of heritability for litter traits by different investigators in different countries for many breeds of rabbits (Lampo and Broeck, 1975; Baselga, Blasco and Garcia, 1982). Also, various reviewed estimates of genetic and/or phenotypic correlations between litter size and litter weight were, in general, positive and significant (Afifi, Galal, El-Oksh and Kadry, 1980; Lukefahr *et al.*, 1983).

The purpose of the present study was to quantify the average genetic, phenotypic and environmental variation and covariation of litter traits in Bauscat and Giza White rabbits.

MATERIAL AND METHODS

The experimental work was carried out at the Experimental Farm of the Faculty of Agriculture at Moshtohor, Zagazig University, Banha Branch, Egypt in the period from October 1975 to September 1983. Rabbits of a foreign breed (Bauscat) and native breed (Giza White) were used. For each breed in the 8 years of production, young does were first mated at the age of 8 months. At the beginning of the breeding season (October) females within each breed were divided at random into groups ranging from three to five does. For each group of does, a buck from the same breed was assigned at random except for the restriction of avoiding matings with full sisters and half sisters (parental or maternal). Each doe was mated to only one sire. According to the breeding plan, each doe was transferred to the buck's hutch to be mated. Hand mating was exercised by restraining the doe to assure copulation. Does were weighed at each mating and palpated 10 days thereafter to determine pregnancy. Does that failed to conceive were returned to the same mating buck to be remated, and were returned to the same buck every other day thereafter until a service was observed. The litter of young rabbits was examined and recorded within 24 h of birth. Following the kindling of the first and all subsequent litters, all does were mated 7 days after each parturition. Weaning was 5 weeks after birth to allow the maximum time for milk feeding. Young doe replacements were added to the herd as needed throughout the course of the study.

Rabbits were always fed *ad libitum* and food was offered three times daily. A dry concentrated diet was provided in the morning and in the evening. The ingredients of this diet were (g/kg) 300 crushed barley, 300 crushed maize, 300 wheat bran, 90 cracked beans, 5 salt and 5 minerals and vitamins. In winter, barseem (*Trifolium alexandrinum*) was supplied at midday. During the summer months, clover hay and green maize plants (*Zea* maize), locally called drawa, were offered instead of barseem. Fresh clean water was available to rabbits at all times.

Litter traits examined were: litter size and weight at birth and at weaning, pre-weaning mortality (%) and mean weight of young at weaning (litter weight at weaning/litter size at weaning). Number of litters born and weaned, respectively were 525 and 451 for Bauscat and 359 and 319 for Giza White. Groups of does to be mated to one buck were chosen at random avoiding half and full sisters. Bucks were allocated at random to groups of does again avoiding half or full-sib mating. Only sires with at least two daughters were included in the analysis. Data were available on 210 does (daughters) by 52 sires. Litter traits in these analyses were considered to be traits of the doe, therefore, the reference to sires in this study means sire of the doe that produced the litter. However, it was not possible to examine simultaneously all factors, and the interactions between them, which were likely to influence rabbit production, because the equations for estimation would have involved a matrix too large to invert. Data were analysed by fitting the following mixed model (Harvey, 1977):

$$Y_{ijklm} = \mu + S_i + D_{ij} + A_k + B_l + e_{ijklm} \quad (1)$$

where:

- Y_{ijklm} = the observation on the *ijklm*th litter;
- μ = the overall mean, common element to all observations;
- S_i = the random effect of *i*th sire of doe;
- D_{ij} = the random effect of *j*th doe nested within a random effect of *i*th sire;
- A_k = the fixed effect of *k*th parity;
- B_l = the fixed effect of *l*th month of kindling;

and

e_{ijklm} = a random deviation of mth litter of ijth doe and assumed to be independently randomly distributed $(0, \sigma_e^2)$. It includes all the other effects not specified in the mixed model.

However, a dependency in the least-squares equations existed when simultaneously fitting year of kindling together with the sire in the same model of analysis. Accordingly, the data were adjusted for year-of-kindling effects. The least-squares constants from using a linear model including the year of kindling as a fixed effect were used to adjust the data. By correcting for year effect before analysing the data, a possible bias may have been introduced. Sire analysis and estimation of genetic and phenotypic parameters were performed by fitting the same linear model (equation 1) to the year-adjusted data of litter traits. Estimates of sire (σ_S^2), does within sire ($\sigma_{D:S}^2$) and within doe (σ_W^2) components of variance and covariance were computed according to method III of Henderson (1953). Heritabilities were estimated for litter traits by the paternal half-sib method (paternal half-sisters), for each breed separately across all parities, as four times the intraclass correlation coefficient between sire groups:

$$h_S^2 = 4\sigma_S^2/(\sigma_S^2 + \sigma_{D:S}^2 + \sigma_W^2) \quad (2)$$

Genetic, phenotypic and environmental correlation coefficients between any two litter traits were computed by using the formulae outlined by Harvey (1977). Approximate standard errors for the heritability and genetic correlation estimates were computed by the LSML76 program of Harvey (1977). The approximate standard errors for heritability and genetic correlation were computed from procedures described by Swiger, Harvey, Everson and Gregory (1964) and Tallis (1959), respectively.

RESULTS AND DISCUSSION

Means and variation of uncorrected records

The means, standard deviations and coefficients of variation of litter traits based on uncorrected data in Bauscat and Giza White breeds are given in Table 1. Litter size at weaning showed higher coefficients of variation than the corresponding trait at birth in both breeds. Similarly, Lukefahr (1982) reported higher coefficients at weaning than at birth (0·225 at birth *v.* 0·270 at weaning). In the present study, the great variation in litter size at weaning may be attributed to differences in litter losses that occurred during the suckling period.

For both breeds litter weight at weaning showed higher coefficients of variation than the corresponding trait at birth (Table 1). The same findings were observed by Lukefahr

TABLE 1

Means, standard deviations and coefficients of variation† of uncorrected litter traits in Bauscat and Giza White records

	Breed							
	Bauscat				Giza White			
Traits	No. of litters	Mean	s.d.	CV	No. of litters	Mean	s.d.	CV
Litter size at birth	525	6·48	2·13	32·86	359	6·36	2·01	30·96
Litter weight at birth (g)	525	330·20	101·00	29·93	359	326·20	94·30	26·85
Weaning litter size	429	4·91	2·03	40·56	311	4·68	1·89	38·74
Weaning litter weight (g)	429	2071·00	914·20	40·19	311	2000·30	887·60	37·90
Mean offspring weight at weaning (g)	526	441·80	153·40	32·79	308	434·30	132·50	27·42
Pre-weaning mortality (%)	525	29·00			359	28·10		

† Coefficient of variation computed as the residual standard deviation divided by the overall least-squares means of a given litter trait (Harvey, 1977).

TABLE 2

Least-squares means, standard errors and tests of significance of factors affecting litter size and weight traits in Bauscat and Giza White rabbits

	Litter size												Litter weight											
	Birth						Weaning						Birth						Weaning					
	Bauscat			Giza White			Bauscat			Giza White			Bauscat			Giza White			Bauscat			Giza White		
	No. of litters	Mean	s.e.	No. of litters	Mean	s.e.	No. of litters	Mean	s.e.	No. of litters	Mean	s.e.	No. of litters	Mean	s.e.	No. of litters	Mean	s.e.	No. of litters	Mean	s.e.	No. of litters	Mean	s.e.
Significance of year of kindling					**			**			***			***			***			***			***	
1975/76	80	6·66	0·238	69	6·94	0·237	72	4·87	0·235	59	4·83	0·236	80	354	11	69	333	11	72	2037	98	59	1888	99
1976/77	104	6·36	0·209	73	6·40	0·230	79	4·62	0·224	61	4·82	0·232	104	338	10	73	337	10	79	1762	94	61	1794	97
1977/78	77	6·19	0·242	59	6·31	0·256	64	4·66	0·249	56	4·39	0·242	77	323	11	59	358	11	64	2071	104	56	1791	101
1978/79	30	6·73	0·389	26	6·77	0·386	23	5·09	0·415	24	4·46	0·370	30	371	18	26	334	17	23	2155	174	24	1804	155
1979/80	25	7·12	0·426	20	5·65	0·440	19	4·05	0·457	17	3·82	0·439	25	350	20	20	320	20	19	1813	191	17	1935	184
1980/81	56	6·20	0·285	41	5·63	0·307	41	4·54	0·311	31	3·71	0·325	56	301	13	41	269	14	41	1702	130	31	1527	136
1981/82	95	6·46	0·219	30	5·53	0·359	86	5·20	0·215	28	4·79	0·342	95	295	10	30	241	16	86	2035	90	28	2282	143
1982/83	58	6·79	0·280	41	6·80	0·307	45	5·93	0·297	35	5·97	0·306	58	348	13	41	366	14	45	3138	124	35	3244	128
Significance of parity no.					*												**			**			***	
1	90	6·28	0·226	63	5·72	0·287	79	4·94	0·283	54	4·31	0·294	90	309	12	65	278	14	79	1841	125	54	1581	147
2	87	6·63	0·218	59	6·60	0·285	80	4·78	0·273	51	4·73	0·240	87	346	12	62	310	14	79	1896	122	51	1808	146
3	99	6·19	0·204	64	6·51	0·262	79	4·78	0·276	58	4·39	0·262	99	328	11	67	327	13	79	2071	122	58	1841	137
4	88	6·48	0·205	53	6·30	0·276	72	5·04	0·270	51	4·88	0·269	88	336	11	54	338	14	73	2249	119	51	2027	139
5	65	6·47	0·240	34	6·40	0·325	60	4·99	0·294	31	4·70	0·353	65	328	13	35	334	17	60	2210	128	31	2269	168
≥6	73	6·39	0·265	65	7·02	0·327	55	5·11	0·332	57	5·37	0·332	73	319	14	67	358	16	55	2453	146	57	2622	161
Significance of month of kindling		***			**			***			***			***			***			***			***	
October and November	79	5·17	0·232	40	5·55	0·334	65	3·50	0·303	37	3·56	0·332	79	257	13	45	268	16	67	1346	131	37	1531	161
December	58	5·92	0·269	39	6·19	0·348	52	4·84	0·334	37	5·00	0·346	58	299	14	42	296	17	52	2184	143	37	2143	165
January	88	6·05	0·224	51	6·41	0·302	78	5·13	0·280	49	4·84	0·296	88	336	12	51	346	15	78	2401	124	49	2128	148
February	82	7·00	0·222	68	6·66	0·359	74	5·70	0·279	62	5·23	0·257	82	361	12	70	344	13	73	2576	124	62	2492	135
March	61	7·30	0·256	50	7·04	0·304	56	5·70	0·311	46	5·74	0·303	61	367	14	50	356	15	55	2442	135	46	2434	151
April and May	134	6·99	0·184	90	6·69	0·346	100	4·84	0·256	71	4·00	0·252	134	345	10	92	336	12	100	1770	115	71	1419	134

(1982). This higher coefficient of variation is more likely to be due to higher maternal effects on the offspring (lactation). The young up to the age of 12 days (when they open their eyes) remained solely on their mothers' milk. Thereafter, until they were weaned, the mothers' milk provided the main supply of nutrients. Thus, the coefficient of variation of litter weight at weaning includes a contribution due to the variation in milk production of dams.

Relative to the number born per litter, mortality from birth to weaning at 5 weeks of age was calculated for each litter. The percentages were subjected to arc-sine transformation before being analysed in order to make variances homogeneous. The overall means were retransformed to the original scale for presentation in Table 1. Results of other Egyptian studies e.g. Emara (1982) have shown higher pre-weaning mortality percentages for the same Giza White and other breeds.

Mean weight of young at weaning for both breeds in the present study showed higher coefficients of variation than those of 0·109 reported by Lukefahr (1982). Lighter average weaning weight in the same breeds have been reported by Afifi, Galal and Kadry (1982) but heavier average weights were reported by Lukefahr, Hohenboken, Cheeke and Patton (1984) for New Zealand White and Flemish Giant rabbits.

The evidence from the differences between the estimates of litter traits studied and those reported by other workers for the same and/ or different breeds of rabbits could possibly be attributed to one or more of the following reasons: (1) the herds were reared under different climatic and managerial conditions, (2) different herds could possibly be genetically different from each other and/or (3) differences in the models of the analysis used.

Estimation of non-genetic effects

Year of kindling. Litter traits studied varied significantly ($P < 0{\cdot}01$ or $P < 0{\cdot}001$) from one year of kindling to another (Tables 2 and 3). Year-of-kindling differences in litter traits are usually associated with differences in climatic conditions, stockman's skill, management of the hutchery, feeding and incidence of diseases, as well as changes in the genetic make-up of the herd during the long periods of breeding.

Parity. No pattern of parity effect on litter size and pre-weaning mortality was observed (Tables 2 and 3). Afifi, Galal, El-Tawil and El-Khishin, (1976b) and Emara (1982) found that the effect of parity on the average number of young surviving to weaning did not show any consistent trend. The current study shows that the differences in parity effects on litter size at birth and at weaning may be due to differential mortality until weaning among litters of different parities. The other investigators noted above reported that litter size at birth increased progressively as parity advanced. Most of the studies reviewed showed a general trend indicating that pre-weaning mortality rate decreased as parity sequence advanced until a definite parity, then increased again in the later subsequent parities. Here, it has been suggested that rabbits' mothering and rearing performance improves with experience, i.e. this is probably a factor of improved milk production with advance of parity.

Litter weight at birth and at weaning and mean weight of young increased ($P < 0{\cdot}01$ or $P < 0{\cdot}001$) up to the sixth parity (Table 2). These results confirm the direct and positive association between litter weight and individual weight of young. This trend is thought to be due to the improvement in the care and ability of the doe to suckle her young with advance in parity. In this respect, Holdas and Szendro (1982) concluded that the milk yield of does increased as parity advanced. Findings for both breeds showed that litters of the first parity were the lightest either at birth or at weaning when compared with the litters of the other parities (Table 2). Similar results were observed by the other Egyptian investigators, mentioned earlier, for litter weight at birth and by Khalil (1980) for litter weight at weaning. These findings can be expected because does in their first parity have just reached sexual maturity and consequently their ovulation rate and their efficiency in providing their young with nourishment and intra-uterine environment during the prenatal development are at their

TABLE 3

Least-squares means, standard errors and tests of significance of factors affecting pre-weaning mortality and mean offspring weight at weaning in Bauscat and Giza White rabbits

	Pre-weaning mortality†				Mean offspring weight at weaning					
	Bauscat		Giza White		Bauscat			Giza White		
	No.	Mean	No.	Mean	No.	Mean	s.e.	No.	Mean	s.e.
Significance of year of kindling		**		***		***			***	
1975/76	80	25·7	69	34·4	71	415	17	59	400	15
1976/77	104	33·6	73	29·2	79	397	16	60	378	15
1977/78	77	29·4	59	25·5	64	468	18	56	428	16
1978/79	30	16·6	26	35·9	22	499	31	24	387	24
1979/80	25	43·7	20	39·1	19	500	33	17	533	29
1980/81	56	43·8	41	46·5	40	396	23	31	419	21
1981/82	95	18·0	30	4·8	86	413	16	28	479	22
1982/83	58	31·7	41	16·0	45	566	22	33	569	21
Significance of parity no.						**			***	
1	90	19·9	65	23·3	79	388	21	55	381	23
2	87	19·6	61	26·1	79	416	20	52	397	22
3	99	31·6	67	30·9	79	446	21	60	442	20
4	88	31·7	54	17·0	73	458	20	52	427	21
5	65	26·2	35	29·3	60	458	22	31	493	27
≥6	73	31·3	66	20·3	55	511	26	58	500	25
Significance of month of kindling		***		***		***			***	
October and November	79	35·5	44	31·9	67	417	22	40	427	24
December	58	17·6	42	14·5	52	459	25	39	462	26
January	88	18·4	51	16·7	78	514	21	49	462	23
February	82	20·3	69	15·8	73	470	21	63	502	20
March	61	22·3	50	15·4	55	445	23	46	427	23
April and May	134	48·8	92	58·8	100	372	19	71	361	20

† The values given are the re-transformed estimates and consequently have no associated standard errors.

TABLE 4

Variance component estimates† (σ^2), and proportions of variation (V) due to random effects for litter traits in Bauscat and Giza White rabbits

	Sire			Doe/sire			Remainder		
Litter traits	d.f.	σ_S^2	V	d.f.	$\sigma_{D:S}^2$	V	d.f.	σ_W^2	V
Bauscat									
Litter size at birth	24	0·04	0·013	99	0·11	0·034	368	3·02	0·953
Litter weight at birth	24	261·05	0·031*	99	67·31	0·008	368	8 125·15	0·961
Litter size at weaning	23	0·23	0·060***	92	†	0·000	299	3·56	0·940
Litter weight at weaning	23	81 032·83	0·122***	92	31 661·66	0·048	299	550 457·98	0·830
Pre-weaning mortality	24	†	0·000	99	†	0·000	368	866·51	1·000
Mean offspring weight at weaning	23	1 256·87	0·072**	92	†	0·000	299	16 197·92	0·928
Giza White									
Litter size at birth	26	0·21	0·061*	59	0·16	0·048	242	2·98	0·891
Litter weight at birth	26	806·78	0·100**	59	648·79	0·080	254	6 612·16	0·820
Litter size at weaning	24	0·20	0·066*	56	0·07	0·025	211	2·73	0·909
Litter weight at weaning	24	131 298·74	0·193***	56	81 729·58	0·120	211	467 007·63	0·687
Pre-weaning mortality	26	56·66	0·091**	59	17·83	0·029	242	548·07	0·880
Mean offspring weight at weaning	24	2 841·75	0·156***	56	506·37	0·028	211	14 860·50	0·816

† Negative variance component estimates set to zero.

lowest level. The lower ability of the doe to suckle her young during the suckling period could be an additional factor.

Month of kindling. Least-squares means given in Tables 2 and 3 show that there was a general tendency for litter size and weight and mean weight of young to be low when kindling took place in the early months of the year of production (October and November) and to increase as month of year of kindling advanced and to decrease again with kindling at the end of the year of production during April and May. This trend has been observed by other Egyptian investigators, e.g. El-Khishin, Badreldin, Oloufa and Kheireldin (1951). Pre-weaning mortality decreased but at an increasing rate, as month of kindling advanced to March and increased thereafter during April and May (Table 3). Afifi *et al*. (1976a) attributed these results to the fact that, during the early months of the year of production, green fodder for the pregnant doe is not available in sufficient quantity and is of lower nutritive value but that as the month of kindling advances fodder becomes more abundant and of high nutritive value and the weather becomes milder. Towards the end of the year of kindling there is a lack of green fodder and the weather becomes warmer and less favourable.

Month-of-kindling effects on most of the litter traits studied were highly significant ($P < 0{\cdot}01$ or $P < 0{\cdot}001$). Differences in pre-weaning mortality due to month-of-birth effects were attributed to differences in nutrition (Schlolaut, 1982), atmospheric temperature (Afifi *et al*., 1976a) and disease conditions (Lukefahr *et al*., 1984) which usually differ from month to month. Differences among results of different investigators for the effect of month of kindling on mortality may be due to differences in the breed groups used, location, management, feeding systems and climatic conditions.

Components of variance and heritability estimates

Results given in table 4 show that the sire of the doe affected significantly all the pre-weaning litter traits, with the exception of litter size at birth and pre-weaning mortality in the Bauscat breed. Most of these findings are similar to those obtained by Dadlani and Prabhu (1971a and b) and Hanrahan and Eisen (1974) in mice. However, a significant sire effect on most of the litter traits indicates that sire-of-doe effects must be seriously considered when undertaking studies on litter traits in rabbits. Consequently, improvement in litter traits of rabbits could be made by selection of sires of does based on their own performances for litter traits. Caution should be exercised in neglecting the sire of the doe, and concentrating only on the service buck, in work on pre-weaning litter traits in rabbits.

The estimates of the sire, doe-within-sire and within-doe components of variance for the different litter traits are shown in Table 4. These results show that estimates of sire, doe-within-sire and error components of variance for litter traits are quite variable between the Bauscat and Giza White data. The proportion of the variance attributable to the sire component for all litter traits of the Giza White breed are larger than the corresponding variances in the Bauscat, i.e. indicating the presence of moderate or high additive genetic variance in the Giza White. This may be due to a reduction in the genetic variation of litter traits through previous selection in the Bauscat breed (French) in its own country while the Giza White (native) have not been subjected to intensive selection programmes in Egypt. Accordingly, estimates of heritability (Tables 5) for litter traits in the Bauscat are generally substantially lower than the corresponding estimates in Giza White rabbits. Therefore, the high variability due to sires shows the possibility for rabbit breeders in Egypt to improve litter traits of this breed through selection. Also, estimates of heritability for most of the litter traits studied showed that these traits are moderately or highly heritable with the exception of litter size at birth and pre-weaning mortality in Bauscat rabbits.

Sire components of variance were substantially larger than doe components for all litter traits studied, except that the reverse occurred for litter size at birth for Bauscat rabbits (Table 4). The smaller proportions of variation in this study due to doe, as opposed to sire effect, reflect a larger environmental component of variance associated with the doe during kindling and raising a litter to weaning. Genetic and environmental differences in pre- and post-natal maternal influences can be an added factor.

Estimates of heritability of litter traits at birth and at weaning (Table 5) indicate that the sire's genetic contribution to litter traits are much higher during the nursing period than for prenatal growth. Higher estimates of heritability for litter size and weight at weaning rather than at birth suggest that selection for litter size and weight at weaning will give greater improvement in these traits than selection at birth (Table 5). Also, these substantial estimates indicate the importance of planning specialized selection programmes for sires. The heritability estimates for litter size and weight at birth and/or at weaning in both breeds, are within the range of estimates cited in the literature.

The negative estimate of heritability for pre-weaning mortality in the Bauscat breed is a reflexion of low sample size which, as shown by Gill and Jensen (1968), could be reduced by increasing the number of sires and the number of daughters (does) per sire as well as using more information per sire instead of using more sires. On the other hand, the moderate estimate of heritability (0·36 s.e. 0·194) for pre-weaning mortality in Giza White rabbits suggests that selection for decreased mortality to weaning should be effective in this breed. This est to be higher than the estir obtained by Rollins, Casady, Sittmann (1963) for New Ze rabbits.

The higher estimate of heritabi weight of young at weaning in rabbits as compared with the Ba 5) indicates that selection for inc weight of young at weaning in rabbits could increase weight o birth and so lead to a greater i kindling difficulty. Therefore, investigation of this problem is requ

The discrepancy between most obtained in this study for heritabili traits and the corresponding reported in the literature may be to the use of different breeds rear particular environmental conditions definite period of time. Statistically, range can be attributed to small with poor structure and to a va statistical models.

Phenotypic correlation. Ph correlations among litter size trait positive and of moderate magnitude 6). These estimates are within the ra 0·45 to 0·68 obtained by Afifi *et al.* (1 data for 2 years of their study. Also, p and moderately high estimates of phen correlation between litter size at birth the corresponding trait at 21 and 56 da age were reported by Rouvier, Pouja and Vrillon (1973) to be 0·69 and 0·5 New Zealand White and 0·50 and 0·41

TABLE 5

Estimates of heritability for litter traits based on paternal half-sibs (h_S^2) in Bauscat and Giza White rabbits

	Bauscat			Giza White		
Litter traits	No. of litters	h_S^2	s.e.	No. of litters	h_S^2	s.e.
Litter size at birth	502	0·05	0·083	338	0·25	0·168
Litter weight at birth	502	0·12	0·104	350	0·40	0·198
Litter size at weaning	425	0·24	0·149	302	0·27	0·185
Litter weight at weaning	425	0·49	0·210	302	0·77	0·286
Pre-weaning mortality	502	†		338	0·36	0·194
Mean offspring weight at weaning	425	0·29	0·162	302	0·62	0·261

† Negative estimates of sire component of variance set to zero.

Fauve de Bourgogne rabbits, respectively. The same authors also reported a high positive phenotypic correlation between litter size at 21 days and litter size at 56 days of age, the estimate being 0·89 for both breeds.

The estimates of phenotypic correlation between litter size and litter weight traits were, in general, positive and relatively moderate or large, with the magnitude of the correlation coefficient decreasing as the age of the litter increased (Table 6). This could indicate that litter size has a high positive effect on litter weight at birth, but at weaning trends become low and a decrease in litter size at birth will tend to decrease slightly litter weight at weaning. Again, higher positive phenotypic correlations between litter size at weaning and litter weight at weaning were observed. Estimates of most investigators e.g. Rouvier *et al.* (1973) showed that litter size and litter weight traits from birth to weaning were positively phenotypically correlated.

The positive phenotypic correlations among litter weight traits given in Table 6 were small in magnitude for Bauscat and Giza White rabbits (0·21 and 0·20, respectively).

Estimates of the phenotypic correlations between litter size either at birth or at weaning and mean weight of young at weaning were negative and relatively low or moderate (Table 6). Also, these estimates show that large-sized litters had lighter mean weight of young at weaning than the small-sized litters. Similar estimates were obtained by Rouvier *et al.* (1973). Also, Lampo and Broeck (1975) reported that the phenotypic correlation between percentage of young weaned and individual weaning weight in Dendermonde White rabbits was negative and small, the estimate being −0·082 (s.e. 0·039).

The negative phenotypic correlations presented in Table 6 between litter weight at birth and mean weight of young at weaning were slightly lower for Giza White than for Bauscat rabbits (−0·20 and −0·42, respectively). The findings were rather different for the correlation between litter weight at weaning and mean weight of young at weaning (0·46 *v.* 0·15 for Giza White and Bauscat rabbits, respectively). The inconsistency may be attributed to litter weight at birth and mean weight of young at weaning being influenced ($P < 0{\cdot}001$) by litter size at birth and since these traits were not adjusted for this effect, negative relationships between the two traits were to be expected.

Genetic correlation. The genetic correlations

TABLE 6

Genetic correlations with standard errors (below diagonal) and phenotypic and environmental† correlations (above diagonal) for litter traits of Bauscat and Giza White rabbits

Litter traits	Litter size at birth		Litter weight at birth		Litter size at weaning		Litter weight at weaning		Pre-weaning mortality		Mean offspring weight at weaning	
Bauscat												
Litter size at birth			0·76	(0·75)	0·52	(0·43)	0·31	(0·25)	0·08	(‡)	−0·47	(−0·34)
Litter weight at birth	0·86	0·280			0·41	(0·38)	0·21	(0·23)	−0·03	(‡)	0·42	(−0·17)
Litter size at weaning	0·92	0·220	0·52	0·305			0·75	(0·62)	0·72	(0·73)	−0·46	(−0·40)
Litter weight at weaning	0·55	0·326	0·19	0·329	1·06	0·062			0·87	(1·12)	0·15	(0·10)
Pre-weaning mortality	‡		‡		0·70	0·236	0·49	0·279			0·03	(0·004)
Mean offspring weight at weaning	−0·96	0·527	−0·94	0·315	−0·66	0·442	0·34	0·419	0·31	0·872		
Giza White												
Litter size at birth			0·73	(0·88)	0·49	(0·52)	0·20	(0·64)	0·14	(0·12)	−0·34	(−0·26)
Litter weight at birth	0·51	0·303			0·39	(0·33)	0·20	(−0·11)	0·03	(0·39)	−0·20	(−0·70)
Litter size at weaning	0·43	0·433	0·81	0·546			0·76	(1·12)	−0·59	(−0·46)	−0·15	(−0·41)
Litter weight at weaning	−0·24	0·400	0·99	0·636	0·66	0·195			−0·67	(−0·54)	0·46	(−0·42)
Pre-weaning mortality	0·20	0·393	−1·26	0·580	−1·10	0·846	−1·21	0·619			−0·24	(−0·01)
Mean offspring weight at weaning	−0·62	0·500	0·95	0·812	0·16	0·380	0·84	0·127)	−0·75	0·483		

† Environmental correlations are given in brackets adjacent to the phenotypic correlation.

‡ Indetermined genetic correlations due to negative estimates of sire component of variance for pre-weaning mortality.

between different litter traits for both breeds showed that most of these relationships were similar (in magnitude and sign) to the corresponding estimates of phenotypic correlations (Table 6). The genetic correlation amongst litter size traits was positive and high (Table 6). This part-whole genetic relationship indicates that selection for litter size at birth would improve litter size at weaning as a correlated response. The positive genetic correlation between litter size at birth and the corresponding trait at weaning for the Bauscat is similar to that obtained by Garcia, Blasco, Baselga and Salvador (1980) for the Californian and by Lahiri and Mahajan (1982) for New Zealand White rabbits. All estimates for Giza White would correspond with the 0·51 (s.e. 0·75) reported by Garcia *et al.* (1980). Rouvier *et al.* (1973) reported positive, moderate, or high genetic correlations between litter size traits at birth, 21 and 56 days of age.

Estimates of genetic correlations among litter size and litter weight traits (Table 6) were, in general, positive and relatively large (except those between litter size at birth and litter weight at weaning in Giza White rabbits). However, estimates of genetic correlations between litter size at birth and litter weight traits at 21 and 56 days of age, reported by Rouvier *et al.* (1973) indicated, in general, that the smallest correlations were with litter trait, measured later in life. These part-whole results indicate that genes affecting litter size and litter weight at birth also have an effect on the corresponding traits at weaning. Therefore, estimates of genetic and phenotypic correlation in the present study offer encouragement to the rabbit breeder to select for litter size and litter weight traits at earlier ages, i.e. at kindling or during the pre-weaning period. Consequently, selection for large size and heavy weight of litters at birth are usually associated with genetic improvement in the coresponding trait at weaning. The positive genetic correlations between litter size at birth and litter weight at birth in both Bauscat and Giza White were higher than estimates reported in the literature such as those of Rouvier *et al.* (1973). The high positive genetic correlation (0·75, s.e. 0·430) between litter weight at birth and litter size at weaning reported by Lahiri and Mahajan (1982) for New Zealand White rabbits, falls within the range of the two estimates of 0·52 (s.e. 0·305) and 0·81 (s.e. 0·546) obtained in this study for Bauscat and Giza White rabbits, respectively. Similarly, Rouvier *et al.* (1973) reported that genetic correlation between litter weight at 21 days and litter size at the corresponding age, and litter size at 56 days of age, were high and positive. High positive genetic correlation between litter size at weaning and litter weight at weaning for the Giza White breed (Table 6) falls within the estimates of 0·62 and 0·764 reported by Garcia *et al.* (1980) and Lahiri and Mahajan (1982), respectively. Since the genetic correlation between litter weight at birth and the corresponding trait at weaning in Giza White rabbits is 0·99 (s.e. 0·636) (Table 6) and the heritability estimate of litter weight at birth is 0·40 (s.e. 0·198) (Table 5), it appears feasible to select breeding does for the weaning weight of the litter at kindling time. This was not the case for the Bauscat rabbits. The inconsistency in the genetic correlations between the two breeds may be attributed to breed differences in milking and mothering ability and in the litter losses which occurred during the suckling period. Rouvier *et al.* (1973) found similar results.

Estimates of the genetic correlation between litter size either at birth or at weaning and mean weight of young at weaning were negative and large (except those between litter size at weaning and mean weight of young at weaning in Giza White rabbits). The pattern indicated that genetic correlation coefficients decrease as the age of the offspring increases (Table 6). Similarly, the results of Rouvier *et al.* (1973) showed a general trend for litter size at birth and 21 days of age to be negatively genetically correlated with the individual mean weight per litter at 21 and 56 days of age. On the contrary, Lampo and Broeck (1975) reported that the genetic correlation between number born alive and individual weaning weight in Dendermonde White rabbits was positive and very low, the estimate being 0·011 (s.e. 0·711). However, the estimated genetic correlations with litter size in the present study indicate that continual selection for increased litter size would result in a correlated decrease in mean weight of young at weaning. However, the positive genetic correlations between litter weight either at birth or at weaning and mean weight of young at weaning, and the opposite genetic relationship between litter size at the two ages and the mean weight of young at weaning (Table 6) lead to the same conclusions as were observed by Rouvier *et al.* (1973). They suggested that the growth rate of the average young rabbit during the pre-weaning period depends less on prolificacy and more on litter weight.

Environmental correlation. Table 6 shows that the magnitude of the correlation coefficients decreased as the age of the young advanced and that environmental correlations between different litter traits measured at weaning were high. These environmental correlations emphasize the large environmental influences the doe has on her litter.

REFERENCES

Afifi, E. A., Galal, E. S. E., El-Oksh, H. A. and Kadry, A. E. 1980. Inter-relationships among doe's weight, litter size, litter weight and body weight at different ages in rabbits. *Egyptian Journal of Animal Production* **20:** 127-136.

Afifi, E. A., Galal, E. S. E., El-Tawil, E. A. and El-Khishin, S. S. 1976a. Litter weight in three breeds of rabbits and their crosses. *Egyptian Journal of Animal Production* **16:** 99-108.

Afifi, E. A., Galal, E. S. E., El-Tawil, E. A. and El-Khishin, S. S. 1976b. Litter size at birth and at weaning in three breeds of rabbits and their crosses. *Egyptian Journal of Animal Production* **16:** 109-119.

Afifi, E. A., Galal, E. S. E. and Kadry, A. E. H. 1982. The effect of breed and some environmental factors on litter traits in rabbits. *7th International Congress for Statistics, Computer Science, Social Demographic Research, Ain Shams University, Cairo, Egypt.*

Baselga, M., Blasco, A. and Garcia, F. 1982. Genetic parameters for economic traits in rabbit populations. *Proceedings of 2nd World Congress on Genetics Applied to Livestock Production, Madrid,* pp. 471-480.

Dadlani, H. V. and Prabhu, S. S. 1971a. Quantitative genetic studies in the mouse (*Mus musculus* L.). I. Litter size. *Journal of Genetics* **60:** 184-191.

Dadlani, H. V. and Prabhu, S. S. 1971b. Quantitative genetic studies in the mouse (*Mus musculus* L.). II. Litter weight. *Journal of Genetics* **60:** 207-213.

El-Khishin, A. F., Badreldin, A. L., Oloufa, M. M. and Kheireldin, M. A. 1951. Growth development and litter size in two breeds of rabbits. *Bulletin, Faculty of Agriculture, Cairo University, Egypt, No. 2.*

Emara, M. E. A. 1982. Effect of crossbreeding on some productive traits in rabbits. *Ph.D. Thesis, Faculty of Agriculture, Moshtohor, Zagazig University, Egypt.*

Garcia, F., Blasco, A., Baselga, M. and Salvador, A. 1980. [Genetic analysis of some reproductive traits in meat rabbits.] *Proceedings 2nd World Rabbit Congress, Barcelona. Annales de Génétique et de Sélection Animale* **12:** 297 (Abstr.).

Gill, J. L. and Jensen, E. L. 1968. Probability of obtaining negative estimates of heritability. *Biometrics* **24:** 517-526.

Hanrahan, J. P. and Eisen, E. J. 1974. Genetic variation in litter size and 12-day weight in mice and their relationships with post-weaning growth. *Animal Production* **19:** 13-23.

Harvey, W. R. 1977. User's guide for LSML76. Mixed model least-squares and maximum likelihood computer program. Ohio State University, Columbus, (Mimeograph).

Henderson, C. R. 1953. Estimation of variance and covariance components. *Biometrics* **9:** 226-252.

Holdas, S. and Szendro, Z. 1982. Milk production of rabbits. *Hungarian Agricultural Review* **32:** 95.

Khalil, M. H. E. 1980. Genetic and environmental studies on some productive traits in rabbits. *M.Sc. Thesis, Faculty of Agricultural Science, Moshtohor, Zagazig University, Egypt.*

Lahiri, S. S. and Mahajan, J. M. 1982. Note on the inheritance of age at first breeding, litter size and weight in rabbits. *Indian Journal of Animal Sciences* **52:** 1148-1150.

Lampo, P. and Broeck, L. van den. 1975. [The influence of the heritability of some breeding parameters and the correlations between these parameters with rabbits.] *Archiv für Geflügelkunde* **39:** 108-211.

Lukefahr, S. 1982. Evaluation of rabbit breeds and crosses for overall commercial productivity. *Ph.D. Thesis, Oregon State University, Corvallis, USA.*

Lukefahr, S., Hohenboken, W. D., Cheeke, P. R. and Patton, N. M. 1983. Doe reproduction and preweaning litter performance of straightbred and crossbred rabbits. *Journal of Animal Science* **57:** 1090-1099.

Lukefahr, S., Hohenboken, W. D., Cheeke, P. R. and Patton, N. M. 1984. Genetic effects on maternal performance and litter pre-weaning and post-weaning traits in rabbits. *Animal Production* **38:** 293-300.

Rollins, W. C., Casady, R. B., Sittmann, K. and Sittmann, D. B. 1963. Genetic variance component analysis of litter size and weaning weight of New Zealand White rabbits. *Journal of Animal Science* **22:** 654-657.

Rouvier, R., Poujardieu, B. and Vrillon, J.-L. 1973. [Statistical analysis of the breeding performance of female rabbits: Environmental factors, correlations and repeatabilities.] *Annales de Génétique et de Sélection Animale* **5:** 83-107.

Schlolaut, W. 1982. *The Nutrition of the Rabbit.* Roche, Animal Nutrition Department, Switzerland.

Swiger, L. A., Harvey, W. R., Everson, D. O. and Gregory, K. E. 1964. The variance of intra-class correlation involving groups with one observation. *Biometrics* **20:** 818-826.

Tallis, G. M. 1959. Sampling errors of genetic correlation coefficients calculated from analysis of variance and covariance. *Australian Journal of Statistics* **1:** 35.

(*Received* 10 *February* 1986—*Accepted* 11 *February* 1987)