GENETIC ASPECTS AND LITTER-SIZE CORRECTION FACTORS FOR POSTWEANING GROWTH IN NEW ZEALAND WHITE AND CALIFORNIAN RABBITS

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An experiment was carried out to determine the genetic variation and covariation in postweaning growth performance (body weights and gain) of New Zealand White (NZW) and Californian (CAL) rabbits. A total number of 2251 rabbits were produced from 175 dams mated to 44 sires. A linear mixed model included the effects of sire and dams within sire (as random effects) and year-season, sex, litter size at birth, parity and all possible interactions (as fixed effects) was used for analysing such data. A set of litter size correction factors for postweaning weights and gains were derived. Weights and gains at different ages in NZW rabbits were slightly higher than in CAL. Coefficients of variation of growth traits at earlier ages were higher than at older ages. Year-season affected (P<0.001) most growth traits studied. Growth performance of NZW and CAL rabbits born during autumn are generally higher than those rabbits born during winter and spring. A curvilinear relationship between parity and growth traits was observed. Body weight traits were curvilinearly associated with litter size, while a quadratic relationship was observed for absolute gain traits. Litter-size correction factors for postweaning body weights of NZW breed were nearly similar to the factors for CAL. The factors for body weight traits increased with the increase of litter size, while inconsistent trend was observed for the factors of absolute gain traits. Variation due to sire, dams within sire and remainder were consistent across the two breeds. Estimates of variation due to the sire effect were small or negative and ranged from 0.0 to 1.2%., while dam variation at all ages were large and ranged from 12.2 to 26.4% for NZW and from 16.7 to 25.2 for CAL. The dam effects in NZW rabbits were large in early ages (5 and 6 weeks) than those of later ages (10 and 12 weeks), but a reverse trend for CAL dams was observed. Sire heritabilities (h^2_S) for different growth traits in NZW and CAL rabbits were low ranging from 0.0 to 0.05, while littermate estimates (h^2_{S+D}) were moderate or high ranging from 0.25 to 0.55. Most estimates of phenotypic correlations among growth traits of NZW and CAL rabbits were mainly positive and of moderate or high magnitude. All

littermate estimates of genetic correlations among growth traits of NZW and CAL rabbits were generally positive and high.

Keywords: rabbits, postweaning growth, correction factors, genetic evaluation.

In the last ten years, new standard breeds of rabbits (New Zealand White and Californian) were introduced to Egypt and used on a large scale commercial production in different areas of Egypt. The New Zealand White and Californian breeds were found to exhibit outstanding maternal abilities as related to maternal behavior, lactation and postweaning growth and survival (El-Maghawry, 1990; Ozimba and Lukefahr, 1991 and Youssef, 1992). Genetic aspects concerning postweaning growth traits of such two exotic breeds raised under the Egyptian conditions are very limited (El-Maghawry, 1990). However, without knowledge of the genetics of postweaning growth of these two breeds, planned improvement of meat rabbits in Egypt cannot be achieved.

In constructing a genetic index for use in sire and dam evaluations for postweaning growth in rabbits, there is a need to account for important non- genetic factors such as litter size which influences the rabbit's performance (Hanna, 1992). Since postweaning growth of rabbits are greatly influenced by litter size, therefore, correcting for its effect on growth traits was deemed to be important. Deriving some sets of litter-size correction factors for postweaning growth traits was not previously attempted.

The purposes of the present study were: (1) to derive some sets of litter- size correction factors to adjust postweaning growth traits of New Zealand White and Californian rabbits raised in Egypt, and (2) to conduct a genetic evaluation for growth traits in these breeds.

MATERIAL AND METHODS

The experimental work of this study was carried out at the rabbitry of the Faculty of Agriculture at Moshtohor, Zagazig University, Banha Branch, Egypt. The experiment was carried out for two consecutive years started in October, 1988.

Breeding Plan and data

Two foreign breeds of New Zealand White (NZW) and Californian (CAL) rabbits were used in this study. At the beginning of the breeding season, females within each breed were grouped at random into groups ranging from 3 to 5 does depending upon the available numbers. For each group of does, a buck from the same breed was assigned at random avoiding

full-sib and half-sib and parent-offspring matings. Allover the two years of the study, each buck was allowed to produce all his litters from the same females. Therefore, the mating design produced several progeny for each successful sire-dam combination. Management and feeding of rabbits in the rabbitry were described by Khalil (1993). Body weights (BW) of individual weaned rabbits were recorded to the nearest gram at 5, 6, 8, 10 and 12 weeks of age. Absolute gains (AG) at intervals of 5-6, 6-8, 8-10 and 10-12 weeks of age were also calculated. A total number of 1275 and 976 weaned rabbits in NZW and CAL, respectively were obtained. NZW and CAL progenies produced were from 24 and 20 sires mated to 94 and 81 dams, respectively.

Statistical Analysis

Data of NZW and CAL breeds were analysed separately using Mixed Model Least- Squares and Maximum Likelihood Mean Weighted (LSMLMW) Program of Harvey (1990).

Data of postweaning growth traits (BW and AG) were analysed by adopting the following mixed model:

$$Y_{ijklmnq} = \mu + S_i + D_{ij} + YS_k + A_l + C_m + P_n + YSA_{kl} + AC_{lm} + AP_{ln} + e_{ijklmnq}$$

Where $Y_{ijklmnq}$ = The observation on the ijklmnqth rabbit; μ= Overall mean; S_i= Random effect of the ith sire; D_{ij}= Random effect of the jth dam mated to the ith sire; YS_k= Fixed effect of kth year-season of birth; A_l= Fixed effect of lth sex; C_m= Fixed effect of mth litter size at birth; P_n= Fixed effect of nth parity; YSA_{kl}= Interaction of kth year-season and l^{th} sex; AC_{lm}= Interaction of lth sex and m^{th} litter size at birth; AP_{ln}= Interaction of lth sex and n^{th} parity, and $e_{ijklmnq}$= Random deviation of qth rabbit of ij^{th} dam and assumed to be independently randomly distributed $(0,\sigma^2_e)$.

The absence of records in some subclasses did not permit the inclusion of some interactions. Also, interaction between random effects (i.e. sire or dam) and other fixed effects (litter size in particular) was not permitted since a part of the genetic effect might be removed. In such a case, downward bias in estimates of genetic parameters along with a biasness in the estimates of correction factors might be attained.

Litter-size correction factors for postweaning weights and gains were constructed by smoothing the curve representing the relationship between least- squares means of growth traits with classes of litter size at birth using third degree polynomial regression analysis. In case of nonsignificant partial cubic regression coefficient, second degree polynomial regression was used

and if the quadratic term was not significant the relationships between litter size and growth traits were examined for linearity. The prediction equations of adjusted- growth traits were estimated as:

$$Y= \mu+ b_L(X-\mu_X)+ b_Q(X-\mu_X)^2+ b_C(X-\mu_X)^3$$

Where Y= The predicted value of a trait, μ= overall least-square mean of a given growth trait (adjusted for effects in the model), b_L, b_Q and b_C= Estimates of partial linear, quadratic and cubic regression coefficients of a given growth trait on litter size, X= Litter size and μ_X= Usually equal to mean of litter size. The multiplicative litter-size correction factors for growth traits (BW and AG) were computed on the basis of modal class (the most frequent class) as:

$C_i= \mu m/\mu i$, where C_i= The multiplicative litter size correction factor, μ_m= The least-square mean of a given growth trait at modal class and μ_i= the predicted average of weight or gain at each class of litter size.

Estimates of variance and covariance components computed by LSMLMW (Harvey, 1990) depends mainly on Method 3 of Henderson. By equating mean squares of random effects to their expectations, estimates of variance components for sires (σ^2_S), dam within sire (σ^2_{S+D}) and remainder (σ^2_e) were obtained. Estimates of sire heritability were computed as: $h^2_S=4\sigma^2_S / (\sigma^2_S+\sigma^2_{S+D}+\sigma^2_e)$, while littermate estimates were calculated as: $h^2_{S+D}=2(\sigma^2_S+\sigma^2_{S+D}) / (\sigma^2_S+\sigma^2_{S+D}+\sigma^2_e)$. The littermate estimates of genetic and phenotypic correlation between any two growth traits were also calculated. The respective standard errors of the heritabilities and genetic correlations were approximated by formula given by Swiger et al. (1964) and Harvey (1990).

RESULTS AND DISCUSSION

Means and variation

Means, standard deviations (SD) and coefficients of variation (CV) of different body weights (BW) and absolute weight gains (AG) in New Zealand White (NZW) and Californian (CAL) rabbits are presented in Table 1. Means of growth traits for both breeds and those estimates reported for the same two breeds raised in Egypt (El-Maghawry et al., 1988; El-Maghawry, 1990; Oudah, 1990; Afifi et al., 1990 and El-Desoki, 1991) are lower than of NZW and CAL rabbits raised in Europe and USA (e.g. Blasco et al., 1983; Niedzwiadek, 1983 and Zimmermann et al., 1988; Ozimba and Lukefahr, 1991).However, low growth means for NZW and CAL rabbits

Table 1: Means, standard deviations (SD) and coefficients of variation (CV) for growth traits of New Zealand White and Californian rabbits

Growth trait	New Zealand White				Californian			
	N	Mean	SD	CV%	N	Mean	SD	CV%
Body weight (BW)								
BW5	1275	554	152	22.5	976	505	150	25.3
BW6	1247	674	165	19.9	950	619	157	21.3
BW8	1201	931	206	16.9	907	857	181	16.4
BW10	1167	1233	268	15.5	884	1143	225	14.2
BW12	1127	1578	356	12.6	851	1483	297	13.4
Absolute gain (AG)								
AG1	1247	117	41	30.0	950	110	34	25.9
AG2	1201	253	93	28.2	907	236	72	23.6
AG3	1167	297	100	24.7	884	284	83	21.1
AG4	1127	342	121	25.0	851	336	107	21.4

in raised Egypt lead to conclude that the potential advantages of postweaning growth for these two exotic breeds are not fully expressed in Egypt.

Weights and gains at different ages in NZW were slightly higher than in CAL (Table 1). However, absolute gain for NZW and CAL in this study as well as in reviewed ones (e.g. Afifi et al., 1990; El-Desoki, 1991 and Youssef, 1992) were higher than those previously reported (e.g. Afifi and Emara, 1990) for local breeds of rabbits (e.g. Baladi, Giza White, Baladi Red, ... etc.). Thus, NZW and CAL rabbits could be used as an effective meat-type breed in Egypt.

Coefficients of variation (CV) for growth traits of NZW and CAL rabbits tended generally to decrease as the rabbit advanced in age (Table 1), i.e. estimates of BW and AG at earlier ages were higher than at older ages. The estimates for NZW and CAL averaged 24.1 and 24.2%, respectively for early ages of postweaning growth (5 and 6 weeks) compared with 17.7 and 16.3% for later ages (e.g. 10 and 12 weeks). Estimates of CV of the Egyptian studies (Khalil et al., 1987; Afifi et al., 1990; EL-Maghawry, 1990; Youssef, 1992) showed a general trend indicating that variation in postweaning body weights of a certain breed of rabbits decreased with advancing of rabbit's age. This trend was expected since rabbits at young age (5 or 6 weeks) are more sensitive to the non-genetic maternal effect (in terms of lactation, mothering ability, litter size and weight) which decrease with advance of age. Such high estimates of CV lead to conclude that improvement of growth traits in rabbits (i.e. BW and AG) through phenotypic selection may be possible.

Year-season of birth

Growth performance in the different year-season combinations were significant for most traits studied. High F-ratios obtained here indicate that year-season of birth is one of the most important non-genetic factors affecting (P<0.001) postweaning growth traits of NZW and CAL rabbits raised in Egypt.

The postweaning growth performance of NZW and CAL rabbits born during autumn were generally higher than those rabbits born during winter and spring (Table 2). In Egypt and for local and exotic breeds, there is a general trend indicating that postweaning growth performance of NZW and CAL rabbits increased from the months of autumn (October, November and December) to the months of winter (January, February and March) then decreased thereafter during April and May. These observations could be explained on the basis of the amount and nutritive value of the available greens and of temperature during these months. These conditions can exert their effects on weaning weight of the rabbits (through the amount of milk produced by the suckling dams) and at later ages (through the quantity and quality of the directly ingested food and the appetite of the young) and on food utilization during the postweaning months (Khalil et al., 1987).

Parity

For both breeds, parity effect constituted a significant source of variation in most growth traits at different ages. Results of El-Maghawry (1990), Afifi and Emara (1990), Afifi et al. (1990) and Youssef (1992) reported that parity effect on postweaning body weights and/or gains were significant for different ages studied (P<0.05 or P<0.001). To detect a clear relationship between parity and growth traits, third degree polynomial regression analysis of growth traits on parity was made. Results of this analysis are presented in Table 3. Partial regression of such analysis showed a curvilinear relationship between parity and growth traits. Accordingly, a curvilinear relationship for parity could be fitted on the data of growth performance of NZW and CAL rabbits raised in Egypt. It was also observed that the curves for weight traits were similar to the curves for gain traits. Reviewed averages of rabbit's body weight in different parities showed a general trend indicating that postweaning body weight increased with advance of parity until certain parity and decreased thereafter.

Most investigators reported that body weight of NZW and CAL rabbits increased from first parity to the third ones and decreased thereafter (e.g. El-Maghawry, 1990). These changes with parity are mostly a reflection of the efficiency of the dam as a mother (especially those associated with the sustained ability of the lactating dam to suckle her young until weaning).

Table 2. Least-squares means and tests of significance of body weights and gains of New Zealand White and Californian rabbits in different year-season and litter size subgroups.

Independent variable	BW5 N	BW5 Mean±SE	BW6 N	BW6 Mean±SE	BW8 N	BW8 Mean±SE	BW10 N	BW10 Mean±SE	BW12 N	BW12 Mean±SE	AG1 Mean±SE	AG2 Mean±SE	AG3 Mean±SE	AG4 Mean±SE
New Zealand White														
Year-season:														
1988-autumn	410	660±18	408	784±20	403	1062±30	398	1369±36	379	1721±45	129±5	276±14	312±13	350±16
1988-winter	187	573±22	183	681±24	170	928±35	158	1237±42	152	1541±52	113±6	251±16	298±15	302±19
1988-spring	149	540±20	131	655±22	105	845±34	90	1057±42	88	1283±52	114±5	188±15	210±15	230±19
1989-autumn					9	1038±76	9	1383±93	9	1875±116		266±35	346±36	497±42
1989-winter	308	605±17	306	722±19	297	972±29	295	1290±35	292	1688±43	119±5	251±13	321±12	403±15
1989-spring	221	565±22	219	669±24	217	885±34	215	1134±41	205	1419±51	99±6	221±15	247±15	285±18
Significance		***		***		***		***		***	***	***	***	***
Litter size at birth:														
≤3	34	747±31	34	871±33	34	1097±44	33	1376±55	32	1696±71	133±9	223±20	287±21	342±25
4	69	626±22	69	742±24	66	993±34	65	1267±41	64	1603±51	119±6	232±15	279±15	343±18
5	95	622±21	94	732±23	89	998±33	88	1289±40	85	1640±49	111±6	260±15	291±14	346±18
6	159	559±18	158	664±20	156	916±30	154	1205±36	148	1549±44	106±5	239±13	288±12	344±16
7	235	537±17	233	641±19	230	902±29	224	1189±35	216	1516±42	105±5	245±13	282±12	322±15
8	377	528±17	365	649±19	351	921±29	345	1237±35	337	1614±42	118±4	254±13	312±12	373±15
≥9	306	500±17	294	618±19	275	860±28	256	1152±34	243	1497±41	114±4	233±13	285±12	340±15
Significance		***		***		***		***		***	***	*	***	***

Table 2. (Cont.)

Independent variable	BW5		BW6		BW8		BW10		BW12		AG1	AG2	AG3	AG4
	N	Mean±SE	N	Mean±SE	N	Mean±SE	N	Mean±SE	N	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE
Californian														
Year-season:														
1988-autumn	407	539±17	311	681±22	307	948±24	296	1261±28	282	1625±36	121±5	256±9	305±11	351±13
1988-winter	160	551±19	155	609±27	133	841±29	127	1127±34	125	1443±43	120±6	235±12	281±13	301±16
1988-spring	112	560±22	75	661±25	59	896±28	56	1103±33	53	1335±42	105±5	215±11	207±13	220±16
1989-winter	122	540±19	256	625±20	256	876±22	265	1199±25	246	1599±33	115±4	247± 8	322±10	406±12
1989-spring	175	497±20	153	619±27	152	805±29	150	1006±33	145	1238±42	81±6	117±12	203±13	234±16
Significance	***		***		***		***		***		***	***	***	***
Litter size at birth:														
≤ 3	31	654±31	31	765±34	29	1064±37	29	1338±43	27	1678±55	122±7	258±15	272±17	321±21
4	47	624±26	46	740±28	42	940±31	41	1209±37	40	1530±48	114±6	215±13	267±15	311±18
5	70	580±24	66	676±26	60	931±29	58	1219±33	57	1523±43	108±6	237±12	283±13	308±16
6	146	530±19	146	629±21	139	831±23	133	1075±27	129	1366±35	109±5	203± 9	245±11	306±13
7	181	520±18	177	604±20	168	811±22	161	1064±26	151	1362±34	97±4	202± 9	247±10	292±12
8	251	474±18	243	568±20	233	787±21	232	1033±25	224	1325±32	102±4	215± 8	245±10	278±12
9	146	501±20	141	611±22	139	866±24	134	1164±28	131	1469±36	110±5	248± 9	285±11	315±13
≥10	104	419±21	100	520±23	97	754±25	96	1023±29	92	1329±37	107±5	231±10	265±11	307±14
Significance	***		***		***		***		***		***	***	***	*

* = $P < 0.05$; *** = $P < 0.001$.

Table 3: Estimates of third degree polynomial regression analysis (b±SE) of body weights and gains on parity and litter size in New Zealand White and Californian rabbits.

Trait	Partial regression coefficients on parity			Partial regression coefficients on litter size		
	Linear (gm/parity) b±SE	Quadratic (gm/parity^2) b±SE	Cubic (gm/parity^3) b±SE	Linear (gm/young) b±SE	Quadratic (gm/young^2) b±SE	Cubic (gm/young^3) b±SE
New Zealand White						
BW5	8.5± 8.6 ns	0.2± 5.1 ns	-27.3± 6.8 ***	-28.7±2.9 ***	4.5±1.5 **	-1.4±0.9 ns
BW6	-2.3± 9.3 ns	0.7± 5.5 ns	-28.6± 7.4 ***	-27.3±3.1 ***	6.2±1.7 **	-1.8±1.1 ns
BW8	-26.1±11.2 *	-4.4± 6.5 ns	-16.7± 8.9 ns	-27.3±3.8 °	3.4±2.0 ns	-2.5±1.3 °
BW10	-57.7±13.9 ***	-18.2± 8.1 *	-5.5±11.3 ns	-22.9±4.8 ***	2.4±2.5 ns	-3.5±1.6 *
BW12	-105.5±17.9 ***	-35.8±10.4 **	-0.6±14.4 ns	-19.2±6.1 **	1.6±3.3 ns	-4.2±2.1 *
AG1	-5.9± 2.6 *	0.8± 1.5 ns	-0.9± 1.9 ns	-0.1±0.8 ns	1.6±0.4 **	-0.6±0.3 *
AG2	-24.4± 5.2 ***	-3.8± 3.1 ns	8.9± 4.2 °	-0.3±1.8 ns	-2.1±0.9 *	-0.3±0.6 ns
AG3	-29.5± 5.5 ***	-12.6± 3.2 ***	8.9± 4.4 °	2.2±1.9 ns	-0.7±0.9 ns	-1.1±0.6 ns
AG4	-47.2± 6.5 ***	-17.0± 3.8	8.2± 5.2 ns	1.8±2.2 ns	0.3±1.2 ns	-0.9±0.8 ns
Californian						
BW5	-13.7±10.2 ns	47.6±14.0 ***		-30.3± 3.3 ***	1.6±1.4 ns	-0.8±0.7 ns
BW6	-20.1±11.4 ns	-10.1± 7.1 ns	2.6±10.0 ns	-31.3±3.4 ***	3.1±1.5 *	-0.9±0.8 ns
BW8	-34.2±12.0 **	0.7± 7.6 ns	-0.6± 9.4 ns	-30.8±3.7 ***	7.3±1.7 ***	-2.0±0.9 *
BW10	-45.7±14.1 **	1.5± 9.0 ns	18.3±11.0 ns	-30.5±4.4 ***	9.9±2.0 ***	-1.9±1.0 ns
BW12	-70.9±17.8 ***	-4.2±11.5 ns	53.1±13.9 ***	-31.5±5.6 ***	12.5±2.5 ***	-2.4±1.3 ns
AG1	-1.7± 2.6 ns	3.6± 1.6 *	-0.6± 2.0 ns	-1.4±0.8 ns	1.1±0.3	-0.1±0.2 ns
AG2	-12.7± 5.1 **	14.5± 3.2 ***	-4.1± 4.0 ns	1.2±1.6 ns	3.4±0.7 ***	-0.6±0.4 ns
AG3	-16.0± 5.6 **	-0.4± 3.6 ns	18.1± 4.4 ***	-7.3±1.7 ns	2.5±0.8 ***	0.1±0.4 ns
AG4	-29.2± 6.9 ***	-3.9± 4.4 ns	29.1± 5.4 ***	-0.8±2.1 ns	2.7±9.9 **	0.2±0.5 ns

* = P<0.05; ** = P<0.01; *** = P<0.001.

Ibrahim (1985), Yamani *et al.* (1991), and Khalil (1993) also confirmed this trend through the fact that milk yield of dam increased as parity advanced.

Litter size at birth

Figures of F-ratios obtained in ANOVA reveal that litter size at birth contributed significantly to the variance of body weights and gains of NZW and CAL rabbits. Therefore, litter size at birth was one of the most important non- genetic maternal factors influencing postweaning growth performance of such two breeds of rabbits. With NZW and CAL rabbits raised in Egypt, El-Maghawry (1990) and Hanna (1992) found that litter size at birth had significant effects (P<0.05 or P<0.01) on body weights and/or gains at different ages. For selection and improvement policies, deriving some sets of litter size correction factors for postweaning weights and gains is recommended, therefore, for NZW and CAL rabbits in Egypt.

Estimates of partial regression coefficients of third degree polynomial regression analysis for growth traits on litter size are given in Table 3. Most estimates indicate that there is a curvilinear relationship between litter size and body weights while a quadratic relationship was observed for absolute gain traits. Least square means presented in Table 2 confirmed this trend where rabbits born in small-sized liters (<5) were heavier in body weight than those born in large-sized litters (>8). Absolute gain of rabbit decreased as litter size at birth increased until a certain litter size (6 or 7 young) and increased thereafter. However, results of the Egyptian studies (e.g. El-Maghawry, 1990; Oudah, 1990 and Hanna, 1992) reveal a general pattern indicating that postweaning body weights and/or gains of NZW and CAL rabbits were lower for those born in large-sized litters than for those born in small- and intermediate-sized litters, i.e. growth of rabbit decreases with the increase of litter size at birth. Ibrahim (1985) found that milk production of doe rabbits increased with the increase of litter size at birth up to 6 young per litter. Khalil *et al.* (1987) attributed the decrease of body weight with the increase of litter size at birth to the fact that each dam has a limited capacity for providing her young with nourishment during pre- and post-natal growth until weaning and accordingly the share of each young decreases and results in light weights. The continuation of the same trend of carry over effect of litter size as a maternal factor on body weight, at a decreasing rate, up to 12 weeks of ages might be due to the fact that the maternal effects do not disappear rapidly after weaning and to the high positive association that exists between body weights at weaning and successive ages, i.e. part-whole relationship.

Litter size correction factors

The most frequent class of litter size (i.e. modal value) in NZW and CAL rabbits was 8 young (Table 2). Multiplicative litter-size correction

factors for postweaning growth traits are presented in Table 4. Correction factors obtained here indicated that the equations of curves for body weights of NZW breed were nearly similar to the equations of curves of weights for CAL and consequently factors used for adjusting NZW records could perhaps be applied to CAL records without substantial loss in accuracy. For both breeds, the adjustment factors showed also that factors for body weights of smaller litter size were generally associated with smaller correction factors compared with weights of larger litter size, i.e. litter-size correction factors for body weights increased with the increase of litter size. On the other hand, inconsistent trends of correction factors for absolute gain traits were observed (Table 4). However, small number of records associated with litter-size classes at smaller and very larger litter sizes made comparison between the two classes less reliable.

Table 4: Litter-size correction factors (CF) for body weights and gains in New Zealand White and Californian rabbits.

Litter-size class	BW5	BW6	BW8	BW10	BW12	AG1	AG2	AG3	AG4
New Zealand White									
≤3	0.699	0.736	0.829	0.877	0.910	0.877	1.047	0.867	1.034
4	0.753	0.791	0.852	0.893	0.921	0.936	1.000	0.948	1.001
5	0.804	0.840	0.875	0.909	0.932	0.975	0.974	0.982	0.990
6	0.850	0.880	0.900	0.926	0.943	0.990	0.966	0.987	0.988
7	0.886	0.907	0.927	0.943	0.955	0.977	0.976	0.992	0.986
8	0.911	0.919	0.955	0.961	0.966	0.938	1.004	1.030	0.975
≥9	0.921	0.914	0.985	0.980	0.978	0.880	1.055	1.147	0.946
Californian									
≤3	0.754	0.747	0.725	0.756	0.801	0.833	0.852	0.794	0.845
4	0.792	0.795	0.803	0.809	0.849	0.882	0.908	0.849	0.884
5	0.834	0.843	0.862	0.856	0.888	0.919	0.943	0.895	0.910
6	0.881	0.888	0.901	0.894	0.915	0.940	0.951	0.928	0.921
7	0.934	0.930	0.928	0.917	0.928	0.943	0.932	0.945	0.915
8	0.993	0.965	0.954	0.926	0.924	0.928	0.889	0.944	0.893
9	1.060	0.992	0.993	0.918	0.905	0.896	0.827	0.926	0.858
≥10	1.138	1.009	1.065	0.896	0.872	0.851	0.756	0.891	0.812

It is evident in the present study that postweaning growth records must be adjusted for linear and quadratic effects of litter size (Table 3) in order to obtain reliable estimates of sire or dam evaluation. Also, deriving some sets of litter size correction factors for postweaning growth traits in different parities is recommended. Moreover, litter size correction factors in different seasons of kindling will lead to an effective and accurate evaluation for postweaning growth in rabbits. Unfortunately, the limited

data set of the present work did not permit to derive these sets of correction factors in different parities or seasons of kindling.

Variance components and heritability estimates

No significant differences due to sire for all growth traits were observed (Table 5). On the other hand, differences due to dams for all growth traits at different ages were highly significant (P<0.001); suggesting an important direct additive genetic effect on these traits. They also indicate the presence of an important maternal and dominance effects (non-additive genetic effects).

The estimates of variance components (σ^2) and percentages of variation (V%) attributable to the sire (σ^2_S), dam within sire ($\sigma^2_{D:S}$) and remainder (σ^2_e) for different growth traits in NZW and CAL rabbits show that variation due to random effects (sire, dam and remainder) in the two breeds of the present study were consistent (Table 5). Small or negative estimates of V% due to sire effect were obtained where they ranged from 0.0% to 1.2%. Results of some Egyptian studies (Khalil et al., 1987; El-Maghawry, 1990; Khalil and Khalil, 1991) show that V% of sire component (i.e. h^2_S) for body weight of local breeds (e.g. Giza White) were greater than those of exotic breeds raised in Egypt (e.g. NZW, CAL, Bouscat, .. etc.). In this respect, Khalil et al. (1987) attributed this trend to the reduction in the sire genetic variability within exotic breeds through previous intensive selection, while local breeds were not subjected to such selection.

For more consistency in V% in both breeds of the present study, large component of variance of dam effects were recorded at all ages comparable to those of sire (Table 5). They ranged from 12.2 to 26.4% for NZW and from 16.7 to 25.2% for CAL rabbits. This larger component of variance of dam effects may be due to variation in additive maternal and non-additive maternal (in terms of lactation, litter size, litter weight, young survival, ... etc.) and possibly due to dominance and other additive and non-additive gene interactions. The contribution of dam effects in NZW rabbits were large in early ages (5 and 6 weeks) than those of later ages (10 and 12 weeks), while a reverse trend for CAL dams was observed (Table 5). In NZW breed, contribution of dam averaged 23.6% at earlier ages (5 and 6 weeks) and 16.8% at later ages (10 and 12 weeks), relative to 20.5% and 23.1% for CAL rabbits. Mgheni et al. (1982) and Khalil et al. (1987) reported that, although non-additive maternal effects (lactation and litter size) decreases in relative importance after weaning, they are still present at sexual maturity and could bring complications, particularly in selection experiments for postweaning growth in rabbits. From the present and reviewed results, it is clear that dam effects could be considered as the major factor affecting postweaning growth in rabbits since additive and non-additive maternal effects are still present up to later ages which reached

Table 5. Variance component estimates (σ^2), percentages of variation (V%) due to random effects and heritability estimates for growth traits in New Zealand White and Californian rabbits

Trait	Paternal half-sibs			Maternal half-sibs			Remainder			Heritabilities	
	df	σ^2_s	V%	df	σ^2_D	V%	df	σ^2_e	V%	$h^2_S \pm SE$	$h^2_{S+D} \pm SE$
New Zealand White											
Body weight											
BW5	23	a	0.0	70	4717	24.5***	1154	14527	75.5	a	0.49±0.081
BW6	23	a	0.0	70	5974	26.4***	1126	16693	73.6	a	0.53±0.085
BW8	23	a	0.0	70	6185	21.0***	1078	23287	79.0	a	0.42±0.076
BW10	23	a	0.0	70	8417	19.3***	1042	35221	80.7	a	0.37±0.073
BW12	23	a	0.0	70	12290	18.0***	1002	55949	82.0	a	0.36±0.071
Absolute gain											
AG1	23	a	0.0	70	297	20.0***	1126	1205	80.2	a	0.39±0.073
AG2	23	72.5	1.2	70	944	15.5***	1078	5089	83.3	0.05±0.040	0.33±0.067
AG3	23	30.0	0.5	70	752	12.2***	1042	5396	87.3	0.02±0.033	0.25±0.058
AG4	23	106.0	1.2	70	1128	13.2***	1002	7311	85.5	0.05±0.042	0.29±0.063
Californian											
Body weight											
BW5	19	131	0.7	61	4051	21.5***	868	14760	77.8	0.03±0.038	0.44±0.085
BW6	19	a	0.0	61	4663	23.2***	840	15402	76.8	a	0.44±0.087
BW8	19	a	0.0	60	4836	22.3***	798	16889	77.7	a	0.44±0.087
BW10	19	a	0.0	60	6429	22.1***	775	22631	77.9	a	0.44±0.087
BW12	19	a	0.0	60	11615	25.2***	742	34522	74.8	a	0.50±0.093
Absolute gain											
AG1	19	0.0	0.0	61	163	16.7***	840	811	83.3	a	0.33±0.074
AG2	19	0.0	0.0	60	630	16.9***	798	3090	83.1	a	0.34±0.075
AG3	19	0.0	0.0	60	924	20.4***	775	3599	79.6	a	0.42±0.084
AG4	19	0.0	0.0	60	1462	22.0***	742	5171	78.0	a	0.44±0.087

[a] Negative estimate of sire variance component set to zero.

21.6% at 12 weeks in the present study. Consequently, marketing of broiler rabbits could be recommend at the age in which maternal effects are becoming small or insignificant.

The hierarchical analyses (covariance between sibs) used for analysing the growth traits in NZW and CAL rabbits have resulted in negative or small estimates of σ^2_S and large estimates of σ^2_D (Table 5), i.e. small or negative estimates of h^2_S or an upward bias in h^2_D have resulted. Similar to the present study, most estimates of σ^2_D (or h^2_D) obtained by some Egyptian investigators (Mostageer et al., 1970; Khalil et al., 1987, El-Maghawry, 1990; Khalil and Khalil, 1991) and by the other non-Egyptian ones (e.g. Niedzwiadek, 1983; Randi and Scossiroli, 1980; Blasco et al., 1982) appear to be much higher than the corresponding estimates of h^2_S reported in the same literature, i.e. contribution of maternal effects and dominance variance was large. However, the dam component of variance includes all of the maternal additive genetic variances, the covariance between direct and maternal additive effects, and both the maternal dominance and maternal environmental variances. These are not included in the sire component of variance. Several authors have reported difficulties with estimation of heritability, stemming from bias due to maternal effects and possibly to dominance effects, sometimes coupled with large sampling errors and non-randomness in the distribution of dams within sire groups (Mostageer et al., 1970; Randi and Scossiroli, 1980 and Khalil et al., 1987). Bias and/or sampling errors were responsible for such biasness in estimates and this bias may be mainly due to maternal and dominance effects while sampling errors were due to the small number of sires and dams used in the analysis. The presence of partial confounding due to distribution of data over two effects (e.g. certain sires or dams were used in one year-season) will lead to such bias.

Sire (h^2_S) and littermate (h^2_{S+D}) estimates of heritability for different growth traits in NZW and CAL rabbits are given in Table 5. The estimates ranged from 0.0 to 0.05 for h^2_S and from 0.25 to 0.55 for h^2_{S+D}. For NZW rabbits, estimates of h^2_{S+D} (full-sibs) for growth traits were moderate or high; averaged 0.47 during the early period of postweaning growth (5 and 6 weeks), while they averaged 0.34 at late stage of postweaning growth (12 weeks). These findings confirm the fact that non-additive maternal effects (in terms of lactation, litter size and weight, young survival, etc.) on the rabbit's growth tend to be very high during the early stages of growth, decreasing thereafter gradually during the later stages of postweaning growth. For CAL rabbits, estimates averaged 0.40 at early ages and 0.46 at later ages. In fact, CAL breed is originated from NZW breed (as dam breed) and consequently a reduction in maternal variation was obtained. Moreover, high lactation ability during suckling period for NZW breed relative to CAL

may be responsible for such high non-additive maternal variation at early ages in NZW breed (Ozimba and Lukefahr, 1991) and consequently higher littermate heritabilities were obtained. In such situation, there is obviously a large effect of maternal genotype and/or maternal environment on the animal's performance during earlier postweaning periods of growth (Khalil et al., 1987). Such evidence of maternal effect may probably due to correlation of rabbit's growth with litter condition (Randi and Scossiroli, 1980). Here, litter size is an example of specific maternal environmental effect life (Khalil et al., 1987). Accordingly, variation within litter sizes of dam could have masked any additive genetic variance, e.i. biasing non-additive genetic variance upward.

Estimates of littermate heritability reported here were higher than the corresponding estimates reported by EL-Maghawry (1990) for NZW and CAL rabbits, while they were lower than those estimates reported by khalil et al. (1987) for Giza White rabbits. Such variation in heritability estimates may be due to the small number of sires and/or dams used in the analysis. However, estimates of h^2_{S+D} include variation among full-sibs caused by additive direct, additive maternal, non-genetic maternal and non-maternal common environmental effects. Accordingly, differences between present and reviewed estimates could be attributed to differences in these components.

Correlations

Analysis of covariance were performed on the data of NZW and CAL rabbits in order to derive estimates of genetic (r_G) and phenotypic (r_p) correlations among growth traits at different ages. Due to the negative estimates of sire component of variance, most estimates of sire genetic correlation were not calculated and consequently littermate correlations were only represented in Table 6. As expected, most correlations indicate that the rp among growth traits in NZW and CAL rabbits were generally higher than the r_G estimates. However, estimates obtained here amongst different growth traits were favourable in terms of the objectives of family selection for increased growth in NZW and CAL rabbits. Most estimates of r_G and r_p show that growth traits in earlier ages were strongly correlated and estimates of correlation tended to decrease in value as the differences between the two ages get larger, i.e. part-whole relationship between any two growth traits existed. Such trend was confirmed by many investigators (e.g. Mostageer et al., 1970; Khalil et al., 1987 and El-Maghawry, 1990). All estimates of r_G and r_p indicated also that genetic growth associations (r_G) were positive and similar in sign to the corresponding phenotypic associations (r_p).

Table 6. Estimates of littermate genetic (r_G) and phenotypic (r_p) correlations among growth traits in New Zealand White and Californian rabbits.

Traits correlated	New Zealand White		Californian	
	$r_G \pm SE$	r_p	$r_G \pm SE$	r_p
BW5 & BW6	0.845±0.046	0.926	0.948±0.018	0.968
BW5 & BW8	0.757±0.072	0.810	0.876±0.045	0.862
BW5 & BW10	0.598±0.111	0.669	0.749±0.087	0.702
BW5 & BW12	0.489±0.134	0.558	0.570±0.130	0.523
BW6 & BW8	0.790±0.063	0.852	0.893±0.038	0.902
BW6 & BW10	0.654±0.098	0.723	0.771±0.079	0.748
BW6 & BW12	0.547±0.122	0.602	0.583±0.127	0.568
BW8 & BW10	0.851±0.047	0.913	0.876±0.044	0.909
BW8 & BW12	0.790±0.067	0.819	0.698±0.097	0.754
BW10& BW12	0.893±0.035	0.936	0.802±0.065	0.899
AG1 & AG2	0.170±0.176	0.205	0.174±0.197	0.212
AG1 & AG3	0.296±0.174	0.135	0.028±0.196	0.126
AG1 & AG4	0.088±0.183	0.045	0.016±0.197	0.085
AG2 & AG3	0.894±0.053	0.626	0.434±0.163	0.530
AG2 & AG4	0.637±0.118	0.440	0.372±0.177	0.373
AG3 & AG4	0.690±0.109	0.583	0.654±0.113	0.630
BW5 & AG1	0.258±0.162	0.128	0.039±0.196	0.007
BW5 & AG2	0.153±0.174	0.004	0.113±0.198	0.146
BW5 & AG3	0.132±0.183	0.028	0.028±0.195	0.107
BW5 & AG4	0.051±0.182	0.076	0.030±0.190	0.040
BW6 & AG1	0.410±0.143	0.372	0.194±0.188	0.207
BW6 & AG2	0.100±0.175	0.025	0.075±0.198	0.097
BW6 & AG3	0.053±0.184	0.059	0.033±0.194	0.077
BW6 & AG4	0.026±0.181	0.081	0.008±0.194	0.058
BW8 & AG1	0.516±0.131	0.423	0.252±0.184	0.277
BW8 & AG2	0.305±0.161	0.485	0.205±0.190	0.305
BW8 & AG3	0.317±0.168	0.330	0.184±0.189	0.144
BW8 & AG4	0.237±0.174	0.268	0.117±0.192	0.098
BW10& AG1	0.536±0.130	0.413	0.227±0.185	0.287
BW10& AG2	0.538±0.126	0.623	0.354±0.175	0.479
BW10& AG3	0.580±0.125	0.644	0.428±0.158	0.495
BW10& AG4	0.410±0.155	0.438	0.344±0.171	0.334
BW12& AG1	0.476±0.141	0.341	0.145±0.189	0.258
BW12& AG2	0.649±0.105	0.650	0.406±0.167	0.526
BW12& AG3	0.712±0.095	0.718	0.554±0.133	0.626
BW12& AG4	0.646±0.105	0.702	0.533±0.136	0.624

Most estimates of r_p among growth traits of NZW and CAL rabbits were mainly positive and of moderate or high magnitude (Table 6). The estimates averaged 0.78 among BW traits and 0.33 among AG traits, while they averaged 0.26 between BW and AG. Such estimates fall within the range of literature (e.g. Mostageer *et al.*, 1970; Khalil *et al.*, 1987; EL-Maghawry, 1990). In practice, high and positive estimates of r_p in the present and reviewed studies among growth traits at different ages give a considerable advantage for rabbit breeders in management and culling decisions.

All littermate estimates of r_G among growth traits of NZW and CAL rabbits were positive and generally high (Table 6). They averaged 0.75 among BW traits and 0.37 among AG traits, while they averaged 0.28 between BW and AG. Estimates of r_G among different growth traits reported for NZW and CAL raised in Egypt (El-Maghawry, 1990) fall within the range of those estimates obtained in the present study. However, r_G estimated from full-sibs for growth traits represents the likeness among littermate caused by additive direct, additive maternal, non- genetic maternal (e.g. litter size, lactation, ... etc.) and non-maternal common environmental effects (e.g. year, season ... etc.). Variation in estimates of littermate correlations in the present and reviewed studies may be due to variation in one or more of these previous components.

In conclusion, estimates of r_G for NZW and CAL obtained here and those reviewed estimates for local breeds (Mostageer *et al.*, 1970; Khalil *et al.*, 1987; Khalil and Khalil, 1991) indicated that genetic correlations among body weight at later ages for local breeds (e.g. Giza White, Baladi, ... etc.) were higher than those for exotic ones (e.g. NZW, CAL, Bouscat,... etc.). This is due to that local breeds were not subjected to any intensive programme of selection. This gives an encouragement for rabbit breeders to improve body weight and gain of their breeds at later ages (i.e. at marketing age) through early selection at younger ages.

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