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GENETIC EVALUATION OF CROSSBREEDING PROJECT INVOLVING SAUDI AND SPANISH V-LINE RABBITS TO SYNTHESIZE NEW MATERNAL LINES IN SAUDI ARABIA: I. PRE-WEANING LITTER, LACTATION TRAITS AND FEEDING PARAMETERS

M.H. Khalil[1], M.L. Garcia[2], S.N. Al-Dobaib[1], A.H.AL-Homidan[1], and M. Baselga[3]

[1]Department of Animal Production & Breeding, College of Agriculture & Veterinary Medicine, El-Qassim, King Saud University, Saudi Arabia; [2]Division de Producción Animal, Dep.Tecnología Agroalimentaria, Uni. Miguel Hernández, 03312 Orihuela, Spain; [3]Departamento de Ciencia Animal, Universidad Politecnica de Valencia, Camino de Vera 14, Apdo 22012, 46071, Spain.

SUMMARY: A four-year crossbreeding project involving Spanish maternal line called V-line (V) and Saudi Gabali (G) rabbits was carried out to produce ten genetic groups of V, G, ½V½G, ½G½V, ¾V¼G, ¾G¼V, (½V½G) ^{2}, (½G½V) ^{2},(¾V¼G) ^{2} and (¾G¼V) ^{2}. Litter size at birth (LSB) and weaning (LSW), litter weight at birth (LWB) and weaning (LWW), pre-weaning litter survival (PLS), total milk yield (TMY), milk conversion ratio (MCR), pre-weaning total (TFC) and daily (DFC) feed consumption per litter, feed conversion ratios per kg of litter weight at weaning (FCRLWW), and conversion ratios of feed to milk (FMCR) or litter gain (FLGCR) were evaluated for 2441 litters of 854 does fathered by 142 sires and mothered by 351 dams. An animal model was used to estimate the heritabilities and a generalized least square procedure was used to estimate direct additive effects (D^I_{V-G}), maternal additive effects (M^D_{V-G}), individual (H^I) and maternal (H^M) heterosis, and direct recombination effect (R^I). Groups of ½G½V and ¾G¼V recorded the highest performances in LSB, LSW, LWB, and LWW, while groups of ¾G¼V and (¾G¼V)^2 recorded the highest litter survival and milk yield. The least values in litter traits were recorded for group of (¾V¼G)^2. Among different crossbred does, genetic group of ¾G¼V recorded relatively the highest feed consumption with favourable feed conversion ratios, while those of (¾V¼G)^2 group recorded the lowest feed consumption per litter with the lowest conversion ratios of feed to litter gain. Estimates of D^I_{V-G} for most litter traits, lactation and feeding parameters were significantly moderate in favour of V-line does; being 1.05 young, 24.7 g, 10.7 litter, 319 g, 0.185, 573 g, -16.9 g, and -0.287 in LSB, LWB, PLS, TMY, MLGCR, TFC, DFC and FMCR, respectively. Considerable significant estimates of M^D_{V-G} were also in favour of V-line dams for LSW (1.02 young) and PLS (9.9 litter). Estimates of H^I for litter traits were positive and most of them were significant ($P<0.05$). Crossbred does were associated with 0.7 young, 44 g, 108 g, 3.3 litter, 257 g, 789 g and 29 g of heterotic effects in LSB, LWB, LWW, PLS, TMY, TFC, and DFC, respectively. The percentages of H^I ranged from 1.0 to 10.8 % for litter and lactation traits, and 3.6 to 12.9 % for feeding parameters. The estimates of H^M were positively moderate and ranged from 4.3 to 11.4% for litter size and weight traits (being 0.81 young, 0.74 young, and 170 g for LSB, LSW, and LWW, respectively), and from -6.8 to 5.0% for feeding parameters. The negative estimates of H^I and H^M for FLGCR were also moderate and favourable.

Keywords: Crossbreeding project, litter traits, lactation, feed consumption and conversion, Animal model.

INTRODUCTION

In Saudi Arabia, a national project was established recently for developing rabbit production and to detect the possibilities of producing meat rabbits under industrialized conditions (Khalil *et al.,* 2002). For this reason, special emphases were paid to construct a genetic improvement programme to develop new lines of meat rabbits convenient for this hot climate country. Some traits like milk yield and components in this project are primary evaluated genetically (Khalil *et al.*, 2004), while others like pre-weaning litter traits and feed consumption and conversions per litter are not. As well known, genetic analysis concerning pre-weaning litter traits and feed consumption and conversion for crossbred rabbits raised in hot climate countries are scarce particularly in the Arabian Gulf areas. Reviewed studies (e.g, Feki *et al.*, 1996; Larzul *et al.*, 2004) reported that feed consumption and conversion traits are useful criteria in selection and/or crossbreeding programmes to improve productivity of doe since these traits are more directly related in these programmes with other litter traits such as litter size at birth or at weaning (Estany *et al*, 1989; Rochambeau *et al*, 1998; Gomez *et al*, 1996; Capra *et al*, 2000; Garcia *et al*, 2000 a & b), litter size at weaning and individual weight at weaning (Moura *et al*, 2001), litter size at weaning and individual weight gain (Gomez *et al.*, 2000), and litter weight at weaning (Salaun *et al.*, 2001; Garreau and Rochambeau, 2003; Khalil *et al.*, 2004).

The objectives of the present study were: (1). To evaluate genetically a crossbreeding project involving Spanish V-line rabbits and Gabali Saudi rabbits which was established to synthesize two new maternal lines in Saudi Arabia, and (2). To estimate direct (D^I_{V-G}) and maternal (M^D_{V-G}) additive effects, direct heterosis (H^I), maternal heterosis (H^M) and direct recombination effect (R^I) for pre-weaning litter traits and some lactational and feeding parameters.

MATERIALS AND METHODS

Animals and breeding plan:

Four-year crossbreeding project was started in September 2000 in the experimental rabbitry, College of Agriculture and Veterinary Medicine, El-Qassim region, King Saud University, to develop two maternal lines of rabbits in Saudi Arabia. Rabbits used in this project represent one desert Saudi breed (Gabali, G) and one exotic breed (Spanish V-line, V). The procedure used to form the first synthetic maternal line was to cross bucks of the Saudi Gabali with does of V line to get the F_1 cross, then does and bucks of F_1 cross were mated to get F_2 and then inter-se mating of F_2 was practiced to get three generations thereafter. The second synthetic maternal line was being developed through crossing Saudi Gabali bucks and V line does to get the F_1 cross, then does of F_1 cross were backcrossed with bucks of V line and then the progeny of the backcross were inter-se mated for three generations. The breeding plan in the project permitted simultaneous production of ten genetic groups as shown in Table 1. The animals for all genetic groups were being selected for litter weight at weaning and individual weight at 84 d using a BLUP methodology under an animal model. Distributions of litters born and weaned in these genetic groups across different years of kindling are presented in Table 1. A total number of 2441 litters were born by 854 does, fathered by 142 sires and mothered by 351 dams. The bucks were randomly assigned to mate the does naturally with the restriction to avoid the matings of animals with common grandparents.

Management and feeding

Rabbits were raised in a semi-closed rabbitry. Breeding does and bucks were housed separately in individual wired-cages. All cages are equipped with feeding hoppers and drinking nipples. In the rabbitry, the environmental conditions were monitored; temperature ranged from 20 to about 32 °C, the relative humidity ranged from 20 to 50 % and photoperiod was 16L: 8D. Young rabbits were weaned at four weeks of age. Rabbits were fed a commercial grower pelleted diet during the whole period. On dry matter (DM) basis, the diet contained 18.5% crude protein (CP), 8.0% crude fiber (CF), 3.0% ether extract (EE) and 6.5% ash. Feed and water were available *ad libitum*.

Data collected

Litter size at birth (LSB) and weaning (LSW), litter weight at birth (LWB) and weaning (LWW), preweaning litter survival (PLS), total milk yield (TMY) and preweaning total (TFC) and daily (DFC) feed consumptions were recorded. Pre-weaning feed consumption per litter was that the amount of feed consumed by the doe plus her puppies during the pre-weaning suckling period. Feed conversion ratios per weight of litter at weaning (FCRLWW) were calculated as kg of feed per

Table 1. Number of litters born and weaned in different genetic groups and years of kindling.

Sire genetic group	Dam genetic group	Doe genetic group	Ordinal number (G)	Litters born in year of kindling 2000	2001	2002	2003	Total	Total litters weaned
V-Line (V)	V-Line (V)	V-line (V)	G_1	42	220	77	44	383	306
Gabali (G)	Gabali (G)	Gabali (G)	G_2	43	123	76	45	287	248
V	G	½V½G	G_3	36	129	43	26	234	197
G	V	½G½V	G_4	26	122	94	38	280	235
V	½G½V	¾V¼G	G_5		39	97	38	174	150
G	½V½G	¾G¼V	G_6		77	104	29	210	187
½V½G	½V½G	$(½V½G)^2$	G_7			47	35	82	69
½G½V	½G½V	$(½G½V)^2$	G_8			68	107	175	154
¾V¼G	¾V¼G	$(¾V¼G)^2$	G_9			42	143	185	140
¾G¼V	¾G¼V	$(¾G¼V)^2$	G_{10}			173	249	431	355
		Total		147	719	821	754	2441	2041

kg of litter weight at weaning, while feed to milk conversion ratios (FMCR) were calculated as kg of feed per kg of milk produced. Feed to litter gain conversion ratios (FLGCR) were calculated as the amount of feed consumed divided by preweaning litter gain per litter, while milk to litter gain conversion ratios (MLGCR) were calculated as kg of litter gain per kg of milk suckled.

Models of analysis

The variance and covariance components of the random effects were estimated by the derivate-free multiple traits restricted maximum likelihood procedure (DFREML) using the VCE software (Kovač and Groeneveld, 2003). The animal model used in analyzing traits of the doe was (in matrix notation):

$$y = Xb + Z_a u_a + Z_p u_p + e$$

Where y = vector of observed lactation trait for does, b= vector of fixed effects of genetic group of doe (ten levels; see Table 1), year-season of kindling (one year season every three months), and physiological status of the doe (five levels depending on the parity order and lactation state at the moment of insemination: 1 for nulliparous, 2 for primiparous lactating, 3 for multiparous lactating, 4 for primiparous non-lactating, 5 for multiparous non-lactating); u_a= vector of random additive effect of the does and sires, u_p= vector of random effects of the permanent environment (permanent non-additive effect); X, Z_a and Z_p are the incidence matrices relating records to the fixed effects, additive genetic effects, and permanent environment, respectively; and e= vector of random residual effects.

The REML estimates of the variance components were used to solve the corresponding mixed models applying the procedure of generalised least squares (GLS) and using the PEST package (Groeneveld, 1990). The solutions got for estimable functions F_i (represented as $\hat{f}$ vector and their matrix of estimated variance-covariance errors, C^{ii}) were used to get the estimates of crossbreeding genetic parameters for the lines used. These estimable parameters are representing the differences between direct genetic effects of the lines ($D^I = D_V^I - D_G^I$), differences between maternal genetic effects of the lines ($M^D = M_V^D - M_G^D$), individual heterosis (H^I), maternal heterosis (H^M) and losses for genetic recombination (R^I) as stated by Dickerson (1992); where D_V^I, D_G^I, M_V^D and M_G^D represent the proportion of V and G genes in the individual doe (I) and dam (D). However, the solution for F_2 is equal to zero and, consequently, the interpretations of $\hat{f}$ in terms of the genetic parameters of the crosses are given in Table 2, where the combination of parameters that explain the effects of the different genetic groups of doe are $D_V^I - D_G^I$, $M_V^D - M_G^D$, H^I, H^M, and R^I. Thus, we have five parameters to estimate, that we call vector z, then:

$$\hat{z} = \left[(D_V - D_G) \quad (M_V - M_G) \quad H^I \quad H^M \quad R^I\right],$$

Since z explain $\hat{f}$ through the following model:

$$\hat{f} = \mathbf{X}'z + \mathbf{e}$$

Then, X = The matrix relating the solutions of doe genetic group effects with the parameters of crossbreeding (Table 2).

Remembering the values of $\mathbf{C}^{ii}$ (*i.e.* the variance-covariance matrix of $\hat{f}$), the generalised least squares solution (GLS) for z, which we call, $\hat{z}$ will be unique:

$$\hat{z} = (\mathbf{X}'(\mathbf{C}^{ii})^{-}\mathbf{X})^{-1}\mathbf{X}'(\mathbf{C}^{ii})^{-}\hat{f}$$

Where: X^1 = The variance-covariance matrix of $\hat{z}$ needed to test the significance of the components of z, C^{ii} = Estimated variance-covariance error matrix.

Table 2. Coefficients for genetic effects and interpretations of the estimable function (EF) as function of the genetic parameters of the crosses[a].

Ordinal number	Doe genetic group	EF[1]	Direct Additive (D^I_{V-G})	Maternal Additive (M^D_{V-G})	Direct heterosis (H^I)	Maternal heterosis (H^M)	Recombination effect (R^I)
1	V-Line (V)	F_1-F_2	1.0	1.0	0.0	0.0	0.0
2	Gabali (G)	F_2-F_2	0.0	0.0	0.0	0.0	0.0
3	½V½G	F_3-F_2	0.5	0.0	1.0	0.0	0.0
4	½G½V	F_4-F_2	0.5	1.0	1.0	0.0	0.0
5	¾V¼G	F_5-F_2	0.75	0.5	0.50	1.0	0.25
6	¾G¼V	F_6-F_2	0.25	0.5	0.50	1.0	0.25
7	$(½V½G)^2$	F_7-F_2	0.5	0.5	0.50	1.0	0.50
8	$(½G½V)^2$	F_8-F_2	0.5	0.5	0.50	1.0	0.50
9	$(¾V¼G)^2$	F_9-F_2	0.75	0.75	0.375	0.50	0.375
10	$(¾G¼V)^2$	F_{10}-F_2	0.25	0.25	0.375	0.50	0.375

[a] D^I_{V-G} (M^D_{V-G}) defined as the difference between direct (maternal) additive effects between V-line and Gabali rabbits; H^I = individual heterosis; H^M maternal heterosis; R^I = losses of genetic recombination.
[1] F_i, solution for the i[th] genetic group of does.

RESULTS AND DISCUSSION

Actual means and variations

To characterize the experiment phenotypically, means, standard deviations, minimum and maximum values for litter traits and lactation and feeding parameters are presented in Table 3. However, wide phenotypic variations in all traits were observed. Values in Table 3 for litter size and weight at birth and weaning showed high size and weight in litter associated with moderate lactation performance, and feeding parameters and litter survival which may be encouraging factors for the rabbit producers in the Arabian Gulf countries to raise V-line rabbits in this area and in other hot climatic areas. In hot climate countries like Egypt, little lower values for litter traits were reported for V-line by Yamani (1994) in Egypt and Testik (1996) in Turkey and much lower values by Khalil and Afifi (2000) and Abd El-Aziz *et al.* (2002) for crossbreeding experiment involving Gabali and New Zealand White rabbits. Such discrepancies among different reviewed studies may be due to the strain or breed used, presence of breed x environment interaction or different experimental methods used.

Global differences among genetic groups

Deviations of each genetic group from Gabali (G_i-G_2) for different litter traits and lactation and feeding parameters are presented in Table 4. These deviations are interesting to show the global performances for V-line, Gabali breed and their different crosses in order to identify the possibilities of using these rabbits as a pure stock or as a simple cross or to be used as a synthetic line. However, results of the present study indicate that involving V-line genes in crossbreeding program with Gabali rabbits in hot climate countries was associated with an improvement in the litter and lactation performances and feeding parameters of the crossbred does obtained.

Table 3: Actual means, standard deviations (SD), and ranges and coefficients of variations (CV) for litter traits, lactation and feeding parameters

Doe trait	No.	Mean	SD	Minimum	Maximum	CV(%)
Litter traits:						
LSB, *young*	2441	8.19	2.74	1	16	33
LSW, *young*	2041	6.82	2.38	1	14	35
LWB, *g*	2440	418.9	138.3	25	800	33
LWW, *g*	2041	3727.0	1543.6	660	11460	41
PLS, *litter*	2041	82.92	20.59	8	100	25
Lactation traits:						
TMY, *g*	1854	4997	1511	1300	10311	32
MLGCR	1854	0.686	0.338	0.110	3.800	49
Feeding parameters:						
TFC, *g*	1854	6862	2126	1366	10000	31
DFC, *g*	1854	245.1	75.9	49.0	357.0	31
FCRLWW	1853	2.164	0.884	0.310	8.910	41
FMCR	1854	1.581	0.689	0.290	6.260	44
FLGCR	1854	2.582	1.286	0.350	9.770	50

Table 4: Deviations of each genetic group from Gabali rabbits (G_i-G_2)+ for litter traits, lactation and feeding parameters.

Doe traits	G_1-G_2	G_3-G_2	G_4-G_2	G_5-G_2	G_6-G_2	G_7-G_2	G_8-G_2	G_9-G_2	G_{10}-G_2
Litter traits:									
LSB, *young*	1.19	1.08	1.12	1.1	0.99	0.71	0.69	0.02	0.03
LSW, *young*	1.02	0.35	1.45	1.19	1.54	1.04	1.4	0.08	0.90
LWB, *g*	26.9	41.1	53.7	41.7	39.9	13.8	29.9	4.4	12.9
LWW, *g*	29.9	554	588	136	578	167.0	192	37	260
PLS, *litter*	0.5	4.7	7.2	2.8	9.1	5.5	8.4	6.3	11.9
Lactation traits:									
TMY, *g*	542	831	627	476	929	575	493	535	753
MLGCR	-0.20	-0.15	-0.10	-0.12	-0.10	-0.22	-0.08	-0.20	-0.18
Feeding parameters:									
TFC, *g*	-491	826	1008	1005	1074	621	851	555	883
DFC, *g*	-17	30	36	37	38	29	31	20	32
FCRLWW	0.11	0.23	0.26	0.42	0.13	0.52	0.16	0.62	0.45
FMCR	-0.38	-0.16	-0.04	0.06	-0.13	-0.19	-0.05	-0.12	-0.14
FLGCR	0.25	0.29	0.32	0.58	0.16	0.74	0.19	0.88	0.59

+ See Table 1 to identify different genetic groups.

V-line does had larger litter size, heavier litter weights, lesser feed consumption, and favourable feed or milk conversion ratios compared to G does (Table 4). These results were expected and reflected the superiority of V-line rabbits in fertility, maternal behavior, milk production, pre-weaning growth and survival. For these aspects, it is necessary to identify the genetic aspects of littering performance and lactation and feeding parameters in G breed taking into account the genetic association between litter traits, milk yield and feed consumed and other pre-weaning litter and growth traits.

Litter and lactation traits in the eight genetic groups of crossbred does ranged from 7.15 to 8.56 young for LSB, 6.08 to 7.54 young for LSW, 389 to 447 g for LWB, 3294 to 4019 g for LWW, 75.4 to 89.2 % for PLS, 4657 to 5110 g for TMY, 0.59 to 0.73 for MLGCR (Table 4). Clear differences among these eight groups of crossbred does were notified for litter and lactation traits. In general, groups of ½G½V and ¾G¼V recorded the highest performances in LSB, LSW, LWB, and LWW, while groups of ¾G¼V and $(¾G¼V)^2$ recorded the highest litter survival and milk yield. The least values in litter traits were recorded for group of $(¾V¼G)^2$. For New Zealand (NZW) as a popular commercial dam breed and crossbred rabbits involving Altex as a developed sire breed in USA, results of Medellin and Lukefahr (2001) for LSW, LWW and survival rate revealed that both LSW and LWW in Altex-dammed and NZW-dammed litters were similar.

Feed consumption per litter in different crossbred does ranged from 7.026 to 7.545 kg during the suckling period (TFC) and 250 to 278 g daily (DFC), while feed conversion ratios ranged from 2.08:1 to 2.57:1 for FCRLWW, 1.54:1 to 1.79:1 for FMCR, and 2.43:1 to 3.15:1 for FLGCR (Table 4). Crossbred does of ¾G¼V recorded relatively higher feed consumption but with favourable feed conversion ratios compared to the other crossbred doe groups (Table 4). On the other hand, crossbred doe groups of $(¾V¼G)^2$ recorded the lowest feed consumption per litter (about 250 g daily) but with lesser conversion ratios of feed to litter gain. Many reviewed studies (e.g. Grobner *et al.*, 1985; Medellin and Lukefahr, 2001) reported a range of feed conversion ratio of 2.4:1 to 5.5:1 for different breeds such as New Zealand White, Altex, Palamino and Chincilla Giant Rabbits. As stated before, Medellin and Lukefahr (2001) in USA found that Altex-sired litters gave an increase in feed efficiency (total litter gain per litter feed intake) by 1.28 kg (P<0.01) compared to NZW-sired litters.

Direct breed additive effects (D^I_{V-G})

Estimates of D^I_{V-G} for most litter traits and lactation and feeding parameters were significantly moderate in favour of V-line does (Table 5). The estimates were found to be 1.05 young, 24.7 g, 10.7 litter, 319.5 g, and 0.185 in LSB, LWB, PLS, TMY, and MLGCR, respectively. The figures attained for feeding parameters were -573 g, -16.9 g, and -0.287 in favour also of V-line does (P<0.05) compared to G does for TFC, DFC and FMCR, respectively. However, line V is a maternal line of rabbits selected for litter size at weaning, being the animals genetically evaluated by a BLUP methodology under an animal-repeatability model (Estany *et al.*, 1989).

The moderate estimates of D^I_{V-G} expressed as percentages ranged from 0.3 to 26.1 % for litter and lactation traits, and from -18.6 to 12.6 % for feeding parameters. Such superiority of V-line does in D^I_{V-G} is due to the long history of selection in this breed for litter size at weaning in Spain and for the fact that the average for this trait is high (Estany *et al.*, 1989). This might be also due to that milk production level in V-line does was higher than in G does. Therefore, V-line rabbits could produce, lactate and converse feed efficiently under hot climatic conditions of Saudi Arabia. An earlier American study by Lukefahr et al (1983a & b) showed that estimates of direct additive effects for pre-weaning litter traits, milk yield and feed consumption per litter were mostly in favour of Californian (CAL) litters vs. litters sired by NZW rabbits. In addition, estimates of direct effects for Flemish Giant (FG) on pre-weaning litters were positive and high compared with direct effects on litters of NZW rabbits. The observed direct effects on pre-weaning litter traits were also reported by the same American study (e.g. Lukefahr *et al.,* 1983 a & b) which indicated a consistent desirable trend associated with using FG as a terminal sire breed. In France, NZW-sired litters had higher estimates of direct additive effects for pre-weaning litter traits than that of CAL-sired litters (Brun, 1993). Khalil and Afifi (2000) in crossing experiment between NZW and Gabali rabbits reported that NZW rabbits had higher estimates of direct additive effects than Gabali rabbits for litter weight at birth and weaning (P<0.01 or P<0.001). The other crossbreeding experiment carried out in Egypt by Abd El-Aziz *et al* (2002) indicated that estimates of direct additive effects for milk production were mostly in favour of NZW relative to Gabali rabbits.

Table 5: Estimates of direct (D^I_{V-G}) and maternal (M^D_{V-G}) additive effects and their standard errors (±SE) for litter traits and lactational and feeding parameters

Doe traits	D^{I}_{V-G}		M^{D}_{V-G}	
	Units±SE	D^{I} %[a]	Units±SE	M^{D} %[b]
Litter traits:				
LSB, *young*	1.050±0.385*	13.1	0.251±0.300^{NS}	3.1
LSW, *young*	-0.087±0.333 ^{NS}	-1.3	1.022±0.262*	15.7
LWB, *g*	24.74±20.76^{NS}	6.1	14.32±15.37^{NS}	3.5
LWW, *g*	10.48±217.3^{NS}	0.3	190.5±172.7^{NS}	5.3
PLS, *litter*	10.75±2.48*	13.4	9.94±2.03*	12.4
Lactation traits:				
TMY, *g*	319.5±250.4	7.2	142.7±202.0	3.2
MLGCR	0.185±0.045*	26.1	0.006±0.039	0.8
Feeding parameters:				
TFC, *g*	-572.6±267.9	-9.2	-68.9±235.9	-1.1
DFC, *g*	-16.9±11.5	-7.6	-0.087±9.35	-0.4
FCRLWW	0.023±0.119	1.1	0.052±0.104	2.6
FMCR	-0.287±0.088*	-18.6	-0.028±0.078	-1.8
FLGCR	0.302±0.171	12.6	0.046±0.15	1.9

[a]D^{I}%= [D^{I} in units / (average of V line and Gabali groups)] x 100.
[b]M^{D} % = [M^{D} in units/(average of V line and Gabali groups)] X 100.
NS= Non-significant, *= P<0.05.

Maternal breed additive effects (M^{D}_{V-G})

Most estimates of M^{D}_{V-G} for litter traits, lactation and feeding parameters were in favour of V-line dams; being 0.25 young, 1.02 young, 14.3 g, 190 g, 9.9 litter,143 g for LSB, LSW, LWB, LWW, PLS, and TMY, respectively (Table 5). These favourable estimates expressed as percentages ranged from 3.1 to 15.7 % for litter traits since the estimates of M^{D}_{V-G} recorded for LSW (15.7%) and PLS (12.4%) were considerable and significant. Crossbreeding experiments carried out in Egypt (Afifi and Khalil, 1989; Khalil *et al,* 1995; Khalil and Afifi, 2000) reported similar results; indicating that estimates of maternal additive effects for pre-weaning litter traits were significant. The negative estimates of M^{D}_{V-G} given in Table 5 for TFC and FMCR indicate that V-line dams genetically consumed relatively lesser feed and converse more during pre-weaning period than G dams.

Maternal additivity in V-line were favourable in most cases for pre-weaning litter traits (Table 5); indicating that crossing of V-line rabbits as dam-breed with G rabbits as a sire-breed gave an advantage in the litter performance to be larger in litter size, heavier in litter weight, and higher in survival rate. This superiority of V-line dams is attributable to favorable maternal abilities (Estany *et al.,* 1989). The maternal superiority of V-line rabbits for most pre-weaning traits compared with other standard breeds has been demonstrated in some European studies (e.g. Garcia *et al.,* 2000b). Results of later authors in Spain evidenced the fact that using V-line as a dam breed produced high performances in litter size and weight and growth rate compared to other dam breeds.

Direct heterosis (H^{I})

Estimates of H^{I} indicated that crossbred does were associated with significant heterotic effects in LSB, LWB, LWW, PLS, TMY, TFC, and DFC (Table 6); being 0.68 young, 44 g, 108 g, 3.3 litter, 257 g, 789 g and 28.6 g, respectively. The Estimates of H^{I} expressed as percentages ranged from 1.0 to 10.8 % for litter and lactation traits, and 3.6 to 12.9 % for feeding parameters as shown in Table 6. These results indicate that crossbred does were associated with favourable heterotic effects on pre-weaning litter traits and milk yield. Different crossbreeding experiments carried out in the Arabian area particularly in Egypt (e.g. Afifi and Emara, 1984; Afifi and Khalil, 1989; Khalil *et al.,* 1995; Khalil and Afifi, 2000; Abd El-Aziz *et al.,* 2002) reported results similar to the present results since heterotic effects were evidenced for litter size, litter weight, and milk yield in most of the possible crossbred does obtained. Consequently, both producers and processors in the Arabian area could potentially benefit economically through using commercial production of crossbred does.

Maternal heterosis (H^M)

The estimates of H^M for most litter traits were significant (Table 6), being 0.81 young, 0.74 young, and 170 g for LSB, LSW, and LWW, respectively. The estimates expressed as percentages ranged from 4.3 to 11.4% for preweaning litter size and weight traits (Table 6). Also, H^M estimates for feeding parameters were somewhat moderate and ranging from -6.8 to 5.0%. However, estimates of H^M in most cases are favourable and indicating that crossbred dams had considerable maternal heterotic effects in terms of larger litter size, heavier litter weight at birth and weaning, favourable feed conversion ratio, and efficient milk to litter gain conversion ratio than their crossbred daughters. Results of different crossbreeding experiments carried out in the Arabian area (*e.g.* Afifi *et al.*, 1976a&b; Afifi and Emara, 1984; Khalil *et al*, 2004) revealed that heterotic effects for pre-weaning litter traits were evidenced in most of the crossbred dams obtained.

Table 6: Estimates of direct (H^I) and maternal (H^M) heterosis and direct recombination losses (R^I) and their standard errors (SE) for litter and lactation traits and feeding parameters.

Doe traits	Direct heterosis		Maternal heterosis		R^I in units±SE
	Units±SE	H^I %[a]	Units±SE	H^M %[b]	
Litter traits:					
LSB, *young*	0.683±0.207*	8.5	0.807±0.358*	10.0	-0.729±1.002 NS
LSW, *young*	0.127±0.182NS	2.0	0.742±0.323*	11.4	-0.755±0.911 NS
LWB, *g*	43.91±10.48*	10.8	17.65±18.14NS	4.3	19.82±51.87 NS
LWW, *g*	108.1±120.1*	3.0	170.4±212.4*	4.8	-105.2±595 NS
PLS, *litter*	3.28±1.44*	4.1	0.162±2.57NS	0.2	0.066±7.2 NS
Lactation traits:					
TMY, *g*	257.4±138.0*	5.8	52.5±212.6	1.2	134.0±561.8
MLGCR	0.007±0.027	1.0	0.050±0.41	7.0	-0.121±0.107
Feeding parameters:					
TFC, *g*	788.9±165.9*	12.7	313.9±257.3	5.0	-99.3±652.0
DFC, *g*	28.6±6.40*	12.9	8.86±9.86	4.0	0.164±25.9
FCRLWW	0.079±0.073	3.9	0.099±0.113	4.9	0.075±0.287
FMCR	0.088±0.055	5.7	0.058±0.085	3.8	-0.143±0.216
FLGCR	0.087±0.105	3.6	-0.164±0.163	-6.8	0.518±0.414

[a]H^I%= [H^I in units / average of V line and Gabali groups] x 100.
[b]H^M%= [H^M in units / average of V line and Gabali groups] x 100.
NS = Non-significant; * = P < 0.05.

Direct recombination effects (R^I):

Estimates of R^I for all pre-weaning litter traits and lactational and feeding parameters in crossbred does were non-significant (Table 6). Moreover, these estimates of R^I were mostly different to estimates of H^I. These estimates of R^I reported that there is a potential advantage to use crossbred does and bucks including V-line genes to develop parental lines (maternal and paternal lines having more available heterosis) to be used in hot climate countries. Similar to the present results, the reviewed values for direct recombination loss in some crossbreeding experiments were often not significant (Khalil *et al.*, 2004). In general, the two-locus model of heterosis reflects dominance effect and half additive-by-additive interaction effects whereas the recombination effect included only half of the additive-by-additive interaction effects (Dickerson, 1992).

Comparing estimates of direct recombination losses with direct heterosis in this work, we found that estimates of direct heterosis for the majority of the studied traits were generally larger than the estimates of direct recombination effects (Table 6). Negative direct recombination losses for feed consumption per litter reveal that crossbred does with V genes could mother does with lower feed consumption than purebred V does when both groups of does were mated to bucks from the same V purebred.

Conclusions: In practice, crossing V-line with G rabbits for several generations was associated with an improvement in litter traits and lactation along with some changes in conversion ratios of milk or feed to litter gain.

The superiority of direct and maternal additive effects in V-line for most pre-weaning traits conclude that V-line does or dams could genetically produce, lactate and converse feed efficiently under hot climatic conditions of Saudi Arabia. Accordingly, crossing V-line rabbits as dam-breed in hot climate Gulf countries with local rabbits of these countries as a sire-breed could be an advantageous for the litter performance to be larger in litter size, heavier in litter weight and higher in milking and feeding efficiencies. The estimates of R^I for all traits studied were not significant.

The favourable estimates of direct and maternal heterosis obtained for pre-weaning litter and lactational traits would be an encouraging factor for the rabbit producers in hot countries to use crossbred does and dams on commercial scale. This notation was evidenced here since crossbred does or dams recorded considerable maternal heterotic effects in most traits studied in terms of larger litter size, heavier litter weight, higher litter survival, favourable lesser feed conversion ratio, and efficient milk to litter gain conversion ratio than their crossbred daughters.
Non-significant recombination effects for all pre-weaning litter and lactation traits and feeding parameters obtained here in the present project gave an impression to conclude that crossbred does resulting from crossing V-line with Saudi Gabali rabbits were associated with little recombination losses which in turn had not adverse effects on the results of the program. Therefore, the synthetic maternal lines to be developed will be characterized by heterotic effects on pre-weaning doe traits such as litter size, litter weight, litter survival, lactation and feed conversion.

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