Genetic evaluation for growth traits and thermo tolerance parameters in synthesizing program of new rabbits

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Abstract

Heterotic components for seven-year crossbreeding program were evaluated for body weights (BW) and daily gains in weight (DG) and thermo tolerance parameters (TTP) in 14 genetic groups of Spanish V-line (V), Saudi Gabali (S), ½V½S, ½S½V, ¾V¼S, ¾S¼V, $(½V½S)^2$, $(½S½V)^2$, $(¾V¼S)^2$, $(¾S¼V)^2$, $((¾V¼S)^2)^2$, $((¾S¼V)^2)^2$, Saudi 1 and Saudi 2. A 14251 rabbit fathered by 106 sires and mothered by 621dams were used. An animal model was used to estimate heritabilities and common litter effects and a generalized least square procedure was used to estimate direct additive effects (G^{I}_{V-S}), maternal additive effects (G^{M}_{V-S}), individual (H^I) and maternal (H^M) heterosis, and direct recombination effects (R^I).

Groups of ¾V¼S, $(¾V¼S)^2$ and Saudi 2 rabbits were the highest in growth performance, while group of $(½S½V)^2$ was the lowest. Deviations of each genetic group from Saudi Gabali rabbits in body and ear temperatures at different ages were limited, while the deviations in respiration rate were significant. Heritabilities for growth traits were mostly moderate and ranging from 0.19 to 0.27 for body weights and from 0.18 to 0.34 for daily gains, while the estimates were not significantly different from zero for ear and body temperatures and about 0.12 for respiration rate. Estimates of direct additive effects for body weights and daily gains were mostly in favour of **V**-line rabbits; reaching 13.1 % for some traits. V line dams showed favorable maternal genetic effects for body weights (ranging from 43.8 g to 81.6 g) compared to the Saudi rabbits. Estimates of direct and maternal additive effects for ear and body temperatures were nearly close to zero, while they were moderate and in favour Gabali by 5.6 to 8.5 % relative to the mid-parent for respiration rate. Direct heterosis for body weights and daily gains were significantly positive and ranging from 4.5 to 9.6 %. The estimates of maternal heterosis were also mainly significantly positive and ranging from 1.5 to 6.0 %. The estimates of direct (maternal) heterosis in grams were 29.1 (34.3), 61.4 (17.5), 69.7 (36.1), 98.6 (52.9) and 124.4 (74.8) for body weights at 4, 6, 8, 10 and 12 weeks of age, respectively. For thermo tolerance parameters, neither individual nor maternal heterosis were significant for ear and body temperatures, while the estimates for respiration rate were favourable since they were significantly negative and ranging from 2.2 to 6.6 %. The estimates of direct recombination effects for most traits were always not significant and indicating favourable losses in heterotic gains obtained.

Keywords: Rabbits, crossbreeding, growth, thermo tolerance, additive effects, heterosis, recombination effect.

Introduction

In the last decade, a co-operative rabbit project was established between Saudi Arabia and Spain and the rabbits of line V were exported from Spain (from Valencia Polytechnic University) to the College of Agriculture and Veterinary Medicine in King Saud University to develop new lines of meat rabbits convenient for hot climate (see the details in Khalil, 2010; Khalil and El-Zarie, 2012). Line V was then crossed with the local Saudi Gabali rabbits for nine generations to produce some maternal and paternal synthetic lines. Reviewed studies concerning genetic analysis for growth traits are available, while thermo tolerance parameters for crossbred rabbits raised in hot climate countries are scarce particularly in the Arabian areas. In this concept, Al-Saef et al (2012) detected the linkage between single molecular markers (RAPD type) and daily gain rate traits and measures of respiration rates and body temperatures as indicator to heat stress resistance using multiple regression analysis.

The objectives of the present study were: (i) To evaluate post-weaning growth traits and thermo tolerance parameters genetically in a crossbreeding project involving Spanish V-line and Gabali Saudi (S) rabbits, and (ii) To estimate direct (G^{I}_{V-S}) and maternal (G^{M}_{V-S}) additive effects, direct (H^I) and maternal (H^M) heterosis and direct recombination effect (R^I) for these traits.

Materials and Methods

Animals and breeding plan

Seven-year crossbreeding project was started in September 2000 in the Experimental Rabbitry, College of Agriculture and Veterinary Medicine, King Saud University in El-Qassim region to develop new lines of rabbits in Saudi Arabia. Rabbits used in this project represent one desert breed (Saudi Gabali, S) and one exotic breed (Spanish V-line, V). The maternal V-line is selected in Spain for the number of young weaned per litter since 1984 using a BLUP methodology under a repeatability animal model and non-overlapping generations (Estany *et al.*, 1989). Details of the procedures and crossbreeding plan used to form these synthetic lines were described by Khalil (2010). The crossbreeding plan in the project permitted simultaneous production of 14 genetic groups as shown in Table 1. The numbers of rabbits obtained in each group are presented in Table 1. A total number of 14251 rabbits fathered by 106 sires and mothered by 621 dams were used.

Table 1. Genetic groups of rabbits and their sires, dams, and grand-dams and the numbers of rabbits weaned and thermo tested in each genetic group

Abbreviation of genetic group	Rabbit genetic group	Sire genetic group	Dam genetic group	Grand-dam group	Rabbits weaned	Rabbits thermo tested
G1	V-line (V)	V-Line	V-Line	V	1302	1302
G2	Saudi (S)	Saudi (S)	Saudi (S)	S	1259	1259
G3	½V½S	V	S	S	1088	1088
G4	½S½V	S	V	V	1355	1355
G5	¾V¼S	V	½S½V	V	828	828
G6	¾S¼V	S	½V½S	S	1091	1091
G7	$(½V½S)^2$	½V½S	½V½S	S	316	316
G8	$(½S½V)^2$	½S½V	½S½V	V	771	771
G9	$(¾V¼S)^2$	¾V¼S	¾V¼S	½S½V	486	486
G10	$(¾S¼V)^2$	¾S¼V	¾S¼V	½V½S	1682	1682
G11	$((¾V¼S)^2)^2$	$(¾V¼S)^2$	$(¾V¼S)^2$	¾V¼S	445	
G12	$((¾S¼V)^2)^2$	$(¾S¼V)^2$	$(¾S¼V)^2$	¾S¼V	1122	
G13	**Saudi 2**	$((¾V¼S)^2)^2$	$((¾V¼S)^2)^2$	$(¾V¼S)^2$	894	
G14	**Saudi 3**	$((¾S¼V)^2)^2$	$((¾S¼V)^2)^2$	$(¾S¼V)^2$	1612	
		Total			**14251**	**10178**

Management and feeding

Rabbits were raised in a semi-closed rabbitry in which the environmental conditions were monitored (the temperature ranged from 20 to about 32 °C, the relative humidity ranged from 20 to 50 % and photoperiod was 16L: 8D). Does were mated 10 days after each kindling. Breeding does and bucks were housed separately in individual wired-cages. Young rabbits were weaned at four weeks of age, ear tagged, weighted, sexed and transferred to standard progeny wire cages. All cages are equipped with feeding hoppers and drinking nipples.

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 set

Live body weights were recorded biweekly at 4 weeks (W4), 6 weeks (W6), 8 weeks (W8), 10 weeks (W10), and 12 weeks (W12) of age, while daily gain in weight were computed at intervals of 4-6 weeks (DG46), 6-8 weeks (DG68), 8-10 weeks (DG810), 10-12 weeks (DG1012), 4-10 weeks (DG410), and 4-12 weeks (DG412) of age. Body temperatures at 6 weeks (BT6) and 12 weeks (BT12), ear temperatures at 6 weeks (ET6) and 12 weeks (ET12), and respiration rates at 6 weeks (RR6) and 12 weeks (RR12) of age were recorded as thermo tolerance parameters. Body and ear temperatures were measured by digital thermometer, while respiration rates were recorded using stopwatch (breath/min).

Model of analysis

The variance and covariance components of the random effects were estimated by DFREML procedure using the VCE software (Kovač and Groeneveld, 2003). The animal model used in analyzing the data was (in matrix notation):

$$\mathbf{y= Xb + Z_a u_a + Z_c u_c + e}$$

Where y = vector of observed trait for the weaned rabbit, b= vector of fixed effects of genetic group of progeny (14 levels; see Table 1), year-season of birth (28 levels), and parity (five levels); u_a = vector of random additive effect of the individual rabbit, u_c = vector of random effects of the litter in which the animal was born (non-additive litter common effect); X, Z_a and Z_c = incidence matrices relating the records to the fixed effects, additive genetic effects, and common litter environment, respectively; and **e** = vector of random residual effects.

The DFREML 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, 2006). The estimable parameters as stated by Dickerson (1992) are representing the differences between direct genetic effects of the lines $(G^I = G_V^I - G_S^I)$, differences between maternal genetic effects of the lines $(G^M = G_V^M - G_S^M)$, individual heterosis (H^I), maternal heterosis (H^M) and losses in genetic recombination (R^I); where G_V^I, G_S^I, G_V^M

and G_S^M represent the proportion of V and S genes in the individual (I) and the dam (M).

Results and Discussion

Actual means and variations

The average individual weights were 654, 1142, 1564, 1974 and 2315 g at 4, 6, 8, 10 and 12 weeks of age. These averages were higher or nearly similar to those values obtained for line V reared in Spain (e.g. García *et al*. 2000; Baselga, 2002), but the present results are nearly similar to those studies when compared to rabbits at 8 weeks of age (1572 g *vs* 1569 g; García *et al*. 2000). For the average daily gain, V line rabbits in Spain were higher than the crossbred rabbits (36.5 g/day for daily gain between weaning and 8 weeks and 37.9 g/day between weaning and 9 weeks of age; García *et al*, 2000).

For both ages studied, the actual means for thermo tolerance characters are quite similar (Table 2). Averages for ear and body temperatures were 38.0ºC and 36.4ºC, respectively and the respiratory rate was about 125 breath/min. Boucher *et al.* (1996) and Rogers *et al.* (2004) reported higher body temperature, although this record is very dependent on the ambient temperature of the farm and the year season. Rogers *et al.* (2004) presented higher respiratory rates than in this experiment. The increase in respiration rate enables the rabbits to dissipate the excess body heat by vaporizing more moisture in the inspired air, and the increase in body temperature may be due to the failure of physiological mechanisms to maintain the thermal balance of the animals (Marai *et al.*, 1996). So, the normal temperatures and respiratory rates exhibited by the pure and crossbred rabbits here indicated a functional thermoregulation system.

Table 2. Means, standard deviations (SD), and ranges for post-weaning growth performance and thermo tolerance characters

Trait		No. of Records	Minimum	Maximum	Average	Standard deviation
Weeks	Abbreviation					
Body weight (g):						
4 weeks	W4	14251	174	1682	654	165
6 weeks	W6	10178	256	2186	1142	258
8 weeks	W8	9313	414	2514	1564	282
10 weeks	W10	8808	614	2988	1974	308
12 weeks	W12	8220	798	3716	2315	326
Daily gain in weight (g/d):						
4-6 weeks	DG46	3102	0.68	72.4	34.0	10.7
6-8 weeks	DG68	9130	0.12	90.6	30.1	10.0
8-10 weeks	DG810	8558	0.21	94.2	30.0	10.4
10-12 weeks	DG1012	7897	0.12	92.2	26.2	11.0
4-10 weeks	DG410	2799	0.14	57.2	31.0	6.6
4-12 weeks	DG412	2652	3.12	56.2	29.4	5.4
Ear temperature (ºC):						
6 weeks	ET6	9212	35.6	39.5	38.05	7.96
12 weeks	ET12	7791	36.0	39.7	38.06	7.84
Body temperature (ºC):						
6 weeks	BT6	9267	34.0	39.0	36.45	7.71
12 weeks	BT12	8022	34.0	39.0	36.41	8.27
Respiration rate (breath/min):						
6 weeks	RR6	9267	82	158	126.2	12.6
12 weeks	RR12	8021	80	155	124.4	12.5

Differences among genetic groups

Deviations of each genetic group from Saudi Gabali rabbits (G_i-G_2) for different post-weaning growth traits and thermo tolerance characters are presented in Tables 3 and 4. These deviations are interesting to show globally the performances of V-line rabbits, Saudi 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. V-line rabbits were heavier in most body weights and daily gains compared to the Saudi rabbits (Table 3). These results showed good performance of V-line rabbits in post-weaning body weights and daily gains and reflecting also the fact that involving V-line genes in crossbreeding program with local rabbits in hot climate countries was associated with an improvement in post-weaning growth performance of the crossbred rabbits obtained.

Clear differences among genetic groups of crossbreds were notified for body weights and daily gains of post-weaning growth (Table 3). In general, groups of ¾V¼S, $(¾V¼S)^2$ and Saudi 2 rabbits were the highest in growth performance, while group of $(½S½V)^2$ was the lowest. Gomez *et al*. (1999) with tri-allelic crossbreeding experiment carried out in Spain using two maternal lines (line V and line A) and one paternal line (line R) found that body weights and gains from 32 to 60 days in lines V and A and their crosses were the lightest, while line R and his crosses were the heaviest.

Deviations of each genetic group from the Saudi rabbits (G_i-G_2) in body and ear temperatures at different ages were limited (Table 4). On the contrary, the deviations of all genetic groups of crossbred rabbits in respiration rate relative to Saudi Gabali rabbits were negatively significant. These negative deviations in respiration rate were favourable and indicating that crossbred rabbits are more thermo tolerant than V-line rabbits. Data reported herein are in accordance with those reported by Khalil *et al* (2002) for another set of data for V-line and Saudi rabbits.

Table 3. Deviations of each genetic group from Gabali rabbits $(G_i-G_2)^+$ for post-weaning growth traits

Genetic group$^+$	**Body weight (g)**					**Daily gain in weight (g/d)**					
	W4	W6	W8	W10	W12	DG46	DG68	DG810	DG1012	DG410	DG412
G_1-G_2	53*	52*	69*	72*	149*	3.4*	3.2*	3.7*	4.9*	6.9*	5.7*
G_3-G_2	40*	47*	58*	69*	109*	4.0*	4.5*	4.7*	4.4*	5.3*	5.6*
G_4-G_2	35*	38*	38	37	76*	2.9*	2.3	2.3	2.8*	2.1	2.5
G5-G_2	35*	48	68*	92*	124*	3.9*	3.9*	4.7*	3.5*	3.2*	4.1*
G6-G_2	29	38*	61*	71*	94*	2.4	3.3*	2.6	2.4	2.4	4.6*
G_7-G_2	29	42	30	54	45*	3.1*	3.5*	3.6*	2.4	3.5*	3.4*
G8-G_2	20	34	30	39	37	2.7*	2.2	2.6*	1.8	2.3	2.4
G9-G_2	34*	49	67*	94*	118*	3.9*	3.9*	4.7*	3.5*	3.2*	4.1*
G_{10}-G_2	23	18	34	43	57*	3.7*	3.1*	2.8*	2.2	4.3*	4.6*
G11-G_2	30*	42	63*	84*	112*	3.9*	3.9*	4.7*	3.5*	3.2*	4.1*
G12-G_2	22	26	38	54	45*	2.7*	2.2	2.6*	2.1	2.3	2.4
G13-G_2 (Saudi 2 - G2)	39*	65*	98*	132*	157*	5.6*	4.6*	4.7*	4.3*	3.0*	6.0*
G14-G_2 (Saudi 3 - G2)	30*	48*	80*	110*	129*	3.2*	3.4*	4.2*	3.9*	3.7*	3.9*

$^+$ Genetic groups as abbreviated in Table 1.
*= P<0.05.

Table 4. Deviations of each genetic group from Gabali rabbits $(G_i-G_2)^+$ for thermo tolerance characters

Genetic group$^+$	**Ear temperature (ºC)**		**Body temperature (ºC)**		**Respiration rate (breath/min)**	
	ET6	ET12	BT6	BT12	RR6	RR12
G_1-G_2	0.20	0.19	0.52	0.61	11*	13*
G_3-G_2	0.80	0.50	0.72	0.64	-12*	-16*
G_4-G_2	0.18	0.20	0.28	0.26	-11*	-9
G5-G_2	0.18	0.30	0.62	0.74	-11*	-17*
G6-G_2	0.82	0.38	0.28	0.43	-12*	-12*
G_7-G_2	0.31	0.72	0.64	0.74	-12*	-18*
G8-G_2	0.21	0.15	0.72	0.56	-12*	-14*
G9-G_2	0.14	0.21	0.52	0.69	-11*	-15*
G_{10}-G_2	0.19	0.18	0.64	0.73	-11*	-13*

$^+$ Genetic groups as abbreviated in Table 1.
*= P<0.05.

Heritabilities and common litter effects

Heritabilities for body weights were mostly moderate and ranging from 0.19 to 0.27, while the estimates for average daily gain ranging from 0.18 to 0.34 (Table 5). Moderate heritabilities obtained here for body weights were nearly similar to those estimates obtained in some studies in Egypt (Iraqi, 2003; Youssef, 2004; Youssef et al, 2009), in Nigeria (Akanno and Ibe 2005), in Spain (Estany *et al*. 1992; Gomez *et al*., 2000), and in Brazil (Ferraz and Eler, 1996).

Ratios of common litter effects for post-weaning body weights and gains were mostly high (Table 5). The estimates were ranging from 0.255 to 0.489 for body weights and from 0.183 to 0.263 for daily gains in weight. The high variances of common litter effects for post-weaning body weights and daily gains in weight gave adverse effects on heterosis of these traits. Ferraz and Eler (1996) found that the magnitudes of common litter effects for post-weaning body weights were moderate with a range between 0.21 and 0.32. Argente *et al* (1999) reported higher common litter effects with a range between 0.52 and 0.58. Ferraz and Eler (1996) reported higher estimates than the ones in this experiment. The ratios of ***c***^{2} were always higher than the heritabilities, and the common litter effect decreases over the time (Table 5). These tendencies agree with the results reported by McNitt and Lukefhar (1996).

Heritabilities for body and ear temperatures were not significantly different from zero along with somewhat low common litter effects (Table 5). On the other hand, the estimates were 0.11 and 0.13 for respiration rates at 6 and 12 weeks of age, respectively.

Table 5. Heritabilities (h^2) and ratios of the variance of the common litter effect to the phenotypic variance (c^2), with their standard errors (±SE) for post-weaning growth traits and thermo tolerance characters

Trait$^+$	h^2±SE	c^2±SE
Body weight (g):		
W4	0.24±0.073	0.489±0.030
W6	0.19±0.025	0.396±0.011
W8	0.27±0.019	0.347±0.010
W10	0.19±0.020	0.285±0.010
W12	0.27±0.023	0.255±0.010
Daily gain in weight (g/d):		
DG46	0.28±0.034	0.253±0.017
DG68	0.34±0.010	0.223±0.008
DG810	0.28±0.011	0.237±0.009
DG1012	0.24±0.008	0.183±0.009
DG410	0.19±0.030	0.227±0.015
DG412	0.18±0.040	0.263±0.019
Ear temperature (ºC):		
ET6	0.05±0.001	0.17±0.004
ET12	0.06±0.001	0.29±0.006
Body temperature (ºC):		
BT6	0.07±0.002	0.12±0.005
BT12	0.04±0.002	0.18±0.006
Respiration rate (breath/min):		
RR6	0.11±0.002	0.18±0.005
RR12	0.13±0.003	0.13±0.006

$^+$Abbreviations of the traits as defined in Table 2.

Direct and maternal additive effects

Most estimates of direct genetic effects for body weights and daily gains were in favour of **V**-line rabbits (Table 6). Differences in direct and maternal genetic effects among the two lines were moderate and reaching 13.1% for DG1012. For direct genetic effects, V line rabbits were significantly heavier by 28.6, 31.1, 62.6, 114.8 and 189.4 g than the Saudi Gabali at 4, 6, 8, 10 and 12 weeks of age, respectively, i.e. direct additive effects were of some importance at all stages of growth. Also, V line rabbits were significantly heavier in maternal genetic effects by 43.8, 46.4, 70.9, 78.5 and 81.6 g than the Saudi Gabali at the same ages. Moreover, both direct and maternal genetic effects were significantly heavier in daily gains in weight by values ranging from 0.9 to 3.37 g at all age intervals studied. This is due to the consequences of that litter sizes in V-line were higher (Baselga, 2002).

In Egypt, Abdel-Ghany *et al*. (2000a&b) noted that direct additive effects from crossing NZW with Baladi Red (BR) or Baladi Black (BB) were consistently in favour of BR or BB for post-weaning body weights and gains. Khalil *et al* (1995) and Khalil and Afifi (2000) indicated that estimates of maternal additive effects for post-weaning growth were significant; reflecting desirable maternal additive effects in NZW rabbits compared to the other breeds used and therefore NZW breed is well recognized in our Arabian area as a suitable dam breed resource with outstanding maternal abilities based on its high milk production. Ali (1998) in crossing of Californian with Egyptian Gabali rabbits reported that maternal additive effects on body weights and daily gains of post-weaning growth up to 16 weeks of age were significantly in favour of Californian rabbits ($P<0.01$ or $P<0.001$). Iraqi et al (2008) found that Gabali breed was superior in direct and maternal additive effects over the V line for body weights (W8 and W12) and daily gains (DG4-8 and DG8-12). Percentages of these estimates relative to the averages of the two purebred parents were 5.2, 6.6, 5.3, 11.1 and 21.3% for W4, W8, W12, DG4-8 and DG8-12, respectively. This superiority of the Gabali breed in growth over the V line is interesting because is complementary to the superiority exhibited by the V line in prolificay. This complementarity is beneficial for the cross between Gabali and V line and for the global performance of the line synthesized (Moshtohor line; Iraqi et al, 2009). Youssef et al (2009) stated that differences in direct additive effects between the V-line and Baladi Red rabbits were in favor of V line rabbits reaching 15.0% (76 g) at 4 weeks and 13.3% (195 g) at 12 weeks and these estimates for daily gains were significant during most age intervals reaching 35.7% (7.19 g/d) in the interval of 10–12 weeks. In Spain, Gomez *et al*. (1999) with line V and A (as maternal lines) and line R (as a paternal line) and their all possible crossbreds found that direct additive effects of line A were higher than in line V by about +127 g for weaning weight, +353 g for 60-day weight, and +13 g per day for daily gain from 22-60 days and stated also that rabbits mothered by V-line dams grew faster significantly than rabbits mothered by R-line dams. Piles et al. (2004) reported significant estimates of direct additive effects for live body weight at 60 days.

The differences in direct and maternal additive effects for body weights and gains among the two breeds lead to state that V-line rabbits could be used in crossbreeding programmes in hot climatic countries. This notation was confirmed from the results obtained for thermo tolerance parameters since all the estimates of direct additive effects for body and ear temperatures and respiration rates were found to be very low; ranging from 1.2 to 2.6 % in favour of Saudi rabbits (Table 6). Similar results were obtained by Khalil *et al.* (2002) for another set of data involving six genetic groups.

Table 6. Estimates of direct (G^{I}_{V-S}) and maternal (G^{M}_{V-S}) additive effects and their standard errors (±SE) for post-weaning growth traits and thermo tolerance characters

Trait	**Direct additive effects** (G^{I}_{V-S})		**Maternal additive effects** (G^{M}_{V-S})	
	Units ± SE	%[a]	Units ± SE	%[b]
Body weight (g):				
W4	28.6±12.3*	4.2	43.8±18.2*	6.5
W6	31.1±14.5*	2.7	46.4±14.5*	2.6
W8	62.6±26.2*	4.1	70.9±21.4*	4.6
W10	114.8±40.3*	5.9	78.5±22.9*	2.5
W12	189.4±45.4*	8.1	81.6±19.9*	7.1
Daily gain in weight (g/d):				
DG46	1.30±2.93*	3.8	0.9±0.29*	2.6
DG68	2.51±1.07*	8.4	1.6±0.66*	6.3
DG810	2.96±0.98*	10.1	2.3±0.66*	7.7
DG1012	3.37±1.01*	13.1	2.1±0.67*	8.0
DG410	3.33±0.79*	10.4	2.9±1.20*	9.3
DG412	2.67±0.53*	9.2	2.4±1.03*	8.2
Ear temperature (ºC):				
ET6	-0.20±0.042^{NS}	1.1	-0.12±0.034^{NS}	1.0
ET12	-0.41±0.045^{NS}	1.3	-0.22±0.036^{NS}	1.1
Body temperature (ºC):				
BT6	-0.30±0.042^{NS}	1.4	-0.49±0.034^{NS}	1.1
BT12	-0.07±0.042^{NS}	1.2	-0.13±0.037^{NS}	1.4
Respiration rate (breath/min):				
RR6	7.13±0.65*	5.6	7.54±0.53*	5.8
RR12	11.26±0.73*	8.5	9.37±0.59*	7.2

[a] G^{I}%= [G^{I} in units / (average of V line and Saudi Gabali groups)] x 100.

[b] G^{M} %= [G^{M} in units/(average of V line and Saudi Gabali groups)] X 100.

NS= Non-significant, *= P<0.05.

Direct and maternal heterosis

The estimates of direct heterosis were significantly positive and ranging from 2.7 to 8.1% for body weights and 3.8 to 13.1% for daily gains (Table 7). The estimates for maternal heterosis were also significantly positive and ranging from 2.6 to 7.1% for body weights and from 2.6 to 9.3% for daily gains. The values of direct (maternal) heterosis in grams were 29.1 (34.3), 61.4 (17.5), 69.7 (36.1), 98.6 (52.9) and 124.4 (74.8) for body weights at 4, 6, 8, 10 and 12 weeks of age, respectively, while the estimates in grams were 2.3 (1.7), 2.8 (1.8), 2.1 (0.5), 2.5 (0.6), 1.8 (1.7) and 1.9 (1.4) for daily gains at age intervals of 4-6, 6-8, 8-10, 10-12, 4-10 and 4-12 weeks, respectively. Results of heterosis obtained in the present study are similar to those estimates obtained in other crossbreeding experiments involving maternal lines (Gómez et al, 1999, 2002; Orengo et al., 2004; Iraqi et al, 2009; Youssef et al, 2009). Afifi et al. (1994) when crossing NZW with Baladi Red rabbits in Egypt found that heterosis percentages ranged from 2.7 to 9.5% for post-weaning body weights and gains. Medellin and

Lukefahr (2001) in USA stated that estimates of direct heterosis for the cross between Altex rabbits and NZW were 66 g for weaning weight at 28 days and 1.7 g/d for average daily gain between 28–70 days ($P<0.01$). For Californian (CA), American Chinchilla (CH) and New-Zealand White (NZ) breeds and nine crosses between them, direct heterosis effects were found for body weights, particularly in the crosses involving the NZ breed, with a magnitude ranging from 5 to 10% of the parental mean (*Ouyed et al, 2011)*. On the contrary, maternal genetic and individual heterosis effects were null or very low for a diallel-crossbreeding scheme among 5 Spanish selected lines of 3 maternal and 2 terminal sire lines (Orengo et al., 2009).

Both estimates of direct and maternal heterosis for ear and body temperatures were low and not significantly different from zero (Table 7). But, the estimates for respiration rates are showing heterotic percentages ranging from 3.2 to 5.1 % ($p<0.05$). These results indicate that crossbred rabbits and those rabbits obtained from crossbred dams are showing little genetic differences in body and ear temperatures, but they are of considerable heterotic effects on respiration rates compared to the rabbits obtained from purebred dams, i.e. genetic differences in respiration rates for crossbred rabbits produced by crossbred or purebred dams are of considerable importance.

Table 7. Estimates of direct (H^I) and maternal (H^M) heterosis and direct recombination effects (R^I) and their standard errors (SE) for post-weaning growth traits and thermo tolerance characters

Trait$^+$	Direct heterosis		Maternal heterosis		R^I in units ± SE
	H^I in units ± SE	H^I %^{a}	H^M in units ± SE	H^M %^{b}	
Body weight (g):					
W4	29.1±15.6*	4.5	34.3±13.4*	5.2	45.7±88.5^{NS}
W6	61.4±13.1*	5.3	17.5±12.5^{NS}	1.5	63.6±65.9^{NS}
W8	69.7±14.2*	4.6	36.1±11.2*	2.4	65.5±70.1^{NS}
W10	98.6±15.1*	5.0	52.9±12.7*	2.6	71.0±76.0^{NS}
W12	124.4±15.9*	5.4	74.8±12.1*	3.2	58.1±82.1^{NS}
Daily gain in weight (g/d):					
DG46	2.3±0.38*	6.8	1.7±0.87*	5.0	5.73±4.19^{NS}
DG68	2.8±0.45*	9.3	1.8±0.75*	6.0	1.60±2.14^{NS}
DG810	2.1±0.46*	7.1	0.5±0.76^{NS}	1.7	1.37±2.07^{NS}
DG1012	2.5±0.47*	9.6	0.6±0.77^{NS}	2.4	1.96±2.09^{NS}
DG410	1.8±0.83*	5.8	1.7±0.63*	5.5	2.63±2.55^{NS}
DG412	1.9±0.71*	6.6	1.4±0.56*	4.8	1.89±2.18^{NS}
Ear temperature (ºC):					
ET6	0.23±0.025^{NS}	0.6	0.42±0.037^{NS}	1.1	0.08±0.093^{NS}
ET12	0.09±0.027^{NS}	0.2	0.19±0.041^{NS}	0.5	0.47±0.101^{NS}
Body temperature (ºC):					
BT6	0.22±0.026^{NS}	0.5	0.09±0.038^{NS}	0.2	0.36±0.094^{NS}
BT12	0.27±0.028^{NS}	0.7	0.14±0.043^{NS}	0.4	0.80±0.107^{NS}
Respiration rate (breath/min):					
RR6	-7.4±0.40*	5.9	-2.8±0.58*	2.2	-11.3±1.47*
RR12	-8.3±0.44*	6.6	-5.1±0.67*	4.1	-13.52±1.69*

$^a H^I$%= [H^I in units / average of V line and Saudi Gabali groups] x 100.

$^b H^M$%= [H^M in units / average of V line and Saudi Gabali groups] x 100.

NS = Non-significant: * = $P < 0.05$.

Direct recombination effects

Recombination effects were always not significant (Table 7). These favourable estimates gave an impression to indicate that crossbred dams including V-line genes could be effective to improve post-weaning growth performance through crossing of V-line with native rabbits. Information in the literature concerning estimates of direct recombination effects for crossbreeding experiments in rabbits are scarce. Most of these available results are contradicted. However, reviewed values for direct recombination loss in some crossbreeding experiments are often not significant (Masoero *et al*, 1992; Khalil *et al* , 2002). On the contrary, Majzlik et al (2007) found that Recombination loss was negative and highly significant for body weights (from -14.72 g to -493.51 g).

Conclusions

1. Synthetic lines of rabbits using V line and Saudi Gabali rabbits are being formed in this project successfully to be convenient in hot climate areas. So, these synthetic lines could be used in commercial farms as a pure line or to be crossed with maternal males to get crossbred does
2. The favourable estimates of direct and maternal heterosis for most growth traits and thermo

tolerance parameters in this study advised the rabbit producers to use crossbred dams on commercial scale in hot climate areas.

3. The recombination losses for growth traits in crossbred rabbits were negligible, and therefore, there is a potential advantage to use crossbred dams and sires including V-line genes to develop parental lines (maternal and paternal) having more heterosis to be used in crossbreeding stratification systems in hot climate countries.

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