CARCASS, LEAN COMPOSITION AND MEAT QUALITY TRAITS IN NEW SAUDI SYNTHETIC LINES OF RABBITS DEVELOPED TO BE ADAPTABLE TO HOT CLIMATES

Al-Saef, A.M., M.H. Khalil, A. H. Al-Homidan, K.A. Al-Sobayil, and S.N. Al-Dobaib

Department of Animal Production & Breeding, College of Agriculture & Veterinary Medicine, Al-Qassim University, Buriedah 51452 P.O.Box 6622, Al-Qassim, Saudi Arabia.

ABSTRACT: A five-year crossbreeding project involving Spanish maternal line called V-line (V) and Saudi Gabali (S) rabbits was carried out to produce 14 genetic groups of V, S, ½V½S, ½S½V, ¾V¼S, ¾S¼V, $(½V½S)^2$, $(½S½V)^2$, $(¾V¼S)^2$, $(¾S¼V)^2$, $(¾V¼S)^2$, $(¾S¼V)^2$, **Saudi 2** (synthesized maternal line), and **Saudi 3** (synthesized paternal line). A total number of 2770 rabbits fathered by 91 sires and mothered by 402 dams were slaughtered and heritabilities and common litter effects for edible and non-edible carcass traits, lean composition and meat quality were estimated using an animal model. Weights of carcass, offal, meat, and bone of the crossbred rabbits were heavier relative to the average of purebred rabbits. Heritability estimates were mostly moderate and ranging from 0.17 to 0.22 for edible carcass traits, 0.12 to 0.22 for non-edible carcass traits, 0.14 to 0.20 for lean composition traits, and 0.12 to 0.36 for meat quality traits. For common litter effects, the respective estimates were mostly moderate or high and ranging from 0.31 to 0.35, 0.29 to 0.39, 0.15 to 0.29, and 0.17 to 0.23. Superiority rates for synthetic **Saudi 2** rabbits were found to be high ranging from 5.7 to 20.5% for slaughter and edible carcass traits, from 13.0 to 22.2% for non-edible carcass traits, 5.1 to 25.7% for tissues compositions, and 0.7 to 28.2% for meat quality traits comparable to purebred Saudi rabbits; the rates for synthetic **Saudi 3** rabbits were also high and ranging from 9.4 to 23.0%, 13.2 to 23.1%, 7.4 to 27.1%, and 1.1 to 32.1%, respectively.

Keywords: Rabbits, Synthetic lines, Carcass, Meat quality, Heritability, Common litter effects, Animal model.

INTRODUCTION

Genetic improvement strategies could considerably increase growth and meatiness in the rabbits (Pla et al., 1998; Piles *et al.*, 2000). In fact, current selection programmes in most parts of the world are selecting for fast growth rates and use of terminal sires, with the goals to improve feed and carcass efficiency (Feki et al., 1994; Lobera et al., 2000; Sánchez *et al.*, 2004). In developed countries, using crossbred terminal sires for growth and carcass traits is necessary synthesize new paternal lines (Masoero et al., 1985, 1992; Pla et al., 1998; Piles *et al.*, 2000). In developing countries and in hot climate countries in particular, reports of genetic analyses for carcass traits and meat quality are unfortunately scarce.

At the beginning of this decade (2000), a co-operative rabbit project was established between Saudi Arabia and Spain. The Spanish V-line rabbits used in this project were imported from Valencia Polytechnic University in Spain to be crossed with Saudi Gabali rabbits.

These synthetic lines have now reached the 7th generation. Some traits in this project such as litter and lactation traits, feeding traits and semen traits have been genetically evaluated (Khalil *et al*., 2004; Khalil *et al*., 2005), while others such as carcass and meat quality traits have not.

The objectives of the present study were (1) to estimate differences among 14 genetic groups in this experiment for carcass and meat quality traits with the goal of developing new maternal and paternal lines suited for hot climates, and (2) to estimate variance components due to genetic and random error effects.

MATERIALS AND METHODS

The five-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 maternal and paternal lines of rabbits. Rabbits used in this project represent one desert Saudi Gabali breed (S) and one exotic Spanish breed (V-line). The maternal V-line was selected in Spain for number of young weaned per litter since 1984 using BLUP with a repeatability animal model and non-overlapping generations (Estany *et al.*, 1989). Details of the procedures and crossbreeding plan used in the project to form these synthetic lines were described by Khalil *et al*. (2005, 2007). The crossbreeding plan permitted simultaneous production of 14 genetic groups as shown in Table 1.

The rabbits were managed with natural mating in a semi-closed rabbitry. In the rabbitry, the environmental conditions were monitored; temperature ranged from 20 to about 32°C, relative humidity ranged from 20 to 50%, and the photoperiod in hours was 16 h light: 8 h dark. At four weeks of age, young rabbits were weaned, ear tagged, weighed, sexed and reared in progeny wire cages equipped with feeding hoppers and drinking nipples. Rabbits were fed a commercial pelleted diet during the whole period. On a dry matter basis, the commercial pelleted diet contained 17.9% crude protein, 15.57% crude fiber, 2.45% ether extract, 58.5 nitrogen free extract, and 6.29% ash.

Data set

Data used in this study were recorded from November 2000 until July 2005. At 12 weeks of age, rabbits representing all 14 genetic groups were randomly slaughtered to obtain carcass traits. A total of 2770 rabbits fathered by 91 sires and mothered by 402 dams were slaughtered. The numbers of rabbits slaughtered from each genetic group are presented in Table 1. According to criteria and terminology for carcass traits and lean composition cited by Blasco et al. (1993), rabbits were dissected for edible parts and non-edible ones. Hot carcasses were weighed and dressing percentages were calculated. The head, fur, offal (representing heart + liver + kidneys) and viscera of the carcasses were also weighed. For lean composition traits, all carcasses were divided longitudinally into two similar halves. The right half was separated into lean, fat and bone. Lean of each half was separated and prepared for chemical analysis. Dry matter (using an air-evacuated oven for 16 h), crude protein (Nitrogen x 6.25), ether extract and ash in the lean were determined according to the A.O.A.C. (1990).

Model for analysis

The animal model (in matrix notation) used for analysing carcass and meat quality traits was:

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

Where y = vector of measurements for the slaughtered rabbits, b = vector of fixed effects of genetic group of slaughtered rabbits (14 levels; see Table 1), and year-season of birth of the slaughtered rabbits (20 levels), sex, parity order of the doe (five levels), and litter size at birth (9 levels); u_a = vector of random additive effect of the individual rabbit, u_c = vector of random effects of the litters in which the animal was born; X, Z_a and Z_c are incidence matrices relating the records to the fixed effects, additive genetic effects, and common litter environmental effects, respectively; and **e** is a vector of random residual effects. Variance components of the random effects were estimated by derivate-free restricted maximum likelihood using MTDFREML (Boldman et al., 1995). Local convergence was considered to be met if the variance of the -2 log likelihoods in the simplex was less than 1 x 10^{-6}. After first convergence, restarts were made to find global convergence with convergence declared when the values of -2 log likelihood did not change to the second decimal. The inverse of the numerator relationship matrix (A^{-1}) was used with $Var(u_a) = A\sigma^2_a$, $Var(u_c) = I\sigma^2_c$ and $Var(e) = I\sigma^2_e$ representing variance components for additive genetic, permanent environmental and error effects, respectively. Heritabilities (h^2) were computed from estimates of variance components as:

$$h^2 = \frac{\hat{\sigma}^2_a}{\hat{\sigma}^2_a + \hat{\sigma}^2_c + \hat{\sigma}^2_e}$$

For comparing synthetic lines developed with purebreds, proportional superiority for each trait for **Saudi 2** or **Saudi 3** relative to purebred Saudi or V line average (SR) was calculated as:

$$SR = \frac{(Saudi\ 2\ \text{average or}\ Saudi\ 3\ \ average - purebred\ \ \text{S or V}\ average)}{Purebred\ \ \text{S or V}\ average} x100$$

A generalized least squares procedure was applied to estimate additive and heterotic effects (direct, maternal, and grand-maternal), direct recombination effects and cyto-plasmatic effects and all estimates obtained will be submitted for publication later.

RESULTS AND DISCUSSION

Comparison of purebreds:

Edible and non-edible carcass traits and lean composition produced from V-line rabbits were mostly better than from Saudi rabbits as V-line rabbits had greater hot carcass weight, offal weight, bone weight and ether extract in meat (Tables 2 - 5). The superiority for **V**-line rabbits was expected and reflect the superiority of this line for growth and survival (Estany et al., 1989; Pla et al., 1996; Garcia et al., 2000a,b). These results suggest the necessity to identify the genetic effects for growth and carcass performances in Saudi rabbits taking into account the genetic association between carcass traits and growth performance.

Comparing crossbreds to purebreds:

Deviations of each genetic group from Saudi Gabali rabbits for carcass and meat quality traits show the overall performances for V-line, Saudi breed and their different crosses which can be used to identify the possibilities of using these rabbits as a pure stock or as a simple cross or to be developed as a synthetic line (Tables 2 - 5). In most cases, the highest deviations were recorded by V-line for HCW (200 g), OW (20 g), BW (28 g) and EE in meat (0.7%), while group of $(½S½V)^2$ was the best for DP (4%) and ash in meat (5.8%) comparable to other genetic groups (Tables 2 - 5). Group of $(¾S¼V)^2$ was superior for PSW (251 g), MW (151 g), FW (4.9 g), MBR (0.39) and CP in meat (1.1 %) relative to Saudi Gabali.

Animals in group $(¾S¼V)^2$ had the heaviest slaughter weight and meat weight with the greatest meat-to-bone ratio and crude protein in meat relative to the other groups (Tables 2 - 5). Group $(½S½V)^2$ had the highest dressing percent and ash in meat.

Crossbred rabbits had some advantages over the purebreds in terms of edible and non-edible carcass traits (Tables 2 and 3). Differences among the 14 genetic groups in dressing percentages (DP) were considerable (P<0.001). The digestive tract develops earlier (Pla *et al.*, 1996), so that line V of the present study had a smaller DP at the same pre-slaughter weight than the crossbred rabbits. Bianospino *et al.* (2004a,b) in Brazil recommended that crossbred rabbits could be used to produce retail cuts and carcass because they would have heavier carcasses and loins without increased fatness. Metzger *et al.* (2004b) in Hungary with Pannon White (P), Pannon Ka (PK), Hycole (H), Zika (Z) rabbits and their crossbreds reported that the most important carcass traits in P rabbits had an advantage. The highest dressing out percentages (P<0.001) were in genetic groups of PK (61.1%) and of P (60.7%), and the lowest percentages were in H rabbits (58.9%; P<0.05).

Offal of the crossbred rabbits was less than in V-line rabbits (Table 2). Liver and heart (offal) are organs of early development and animals with high growth rate have an earlier development (Gomez *et al.*, 1998). Gomez *et al.* (1998) found that liver and heart weights for rabbits of line R were heavier than for line V. Results in the literature comparing breeds of large-size with small-size breeds and straightbreds with crossbreds for carcass traits are not consistent (Lukefahr *et al.*, 1982, 1983; Ozimba and Lukefahr, 1991; Pla *et al.*, 1996; Bianospino *et al.*, 2004a,b) because measurements were made at different slaughter weights but differences can be partially due to true genetic differences between breeds.

Measurements for carcass traits (LW, BW, FW, and MBR) in V-line and crossbred rabbits have been shown to be different (P<0.05) in favour of crossbreds (Table 4). MBR was greater with earlier maturity and consequently crossbred rabbits had greater MBR than V-line rabbits (Pla *et al.*, 1996). Although the fat content of the carcass in rabbits is low relative to other animals, fat deposited in the carcass of crossbred rabbits was greater than that in V-line rabbits (Table 4). However, fat deposits increases with age. Similar breed differences in fat deposited in the carcass have been found by Gomez *et al.* (1998) and Metzger *et al.* (2004a,b). Pla *et al.* (1996) in Spain stated that R-line rabbits had fat percentages than line V. Metzger *et al.* (2004a) in Hungary found that MBR in four genetic groups of Hyplus hybrid, purebred Pannon White rabbits and their crossbreds were nearly similar (about 2.7). In another experiment in Hungary, Metzger *et al.* (2004b) using Pannon White (P), Pannon Ka (PK), Hycole (H), Zika (Z) rabbits and their crossbreds reported significant differences among the genetic groups for fat content of the carcass (P<0.05); the lowest the early-maturing group (Z) not the smallest MBR (1.4%), the early-maturing genetic groups were PK (1.8%) and P (1.8%).

Estimates of DM, CP, EE and ash contents in the lean were in favour of crossbreds relative to purebreds (Table 5). In Hungary, Metzger *et al.* (2004a) with four genetic groups found that differences in protein and ash contents of the lean were small but fat content in the lean was smallest for the crossbred rabbits.

Improvement for carcass traits, carcass composition traits and meat quality traits for crosses in the present study were expected and could be useful especially for use in a crossbreeding program of rabbits to get crossbred on a large commercial scale.

Comparing synthetic Saudi 2 and Saudi 3 lines with purebreds:

Saudi 2 and **Saudi 3 were superior for** the majority of edible and non-edible carcass traits, carcass composition and meat quality traits. Differences from other crossbred groups were significant (P<0.05 or P<0.01) (Table 6). Largest superiorities of **Saudi 2** rabbits were 13.1, 20.5, 8.9, 13.0, 14.9, 22.2, 10.8, 25.7, 17.8, 8.2, 28.2 and 20.0% for PSW, HCW, OW, HW, FURW, LW, VW, MW, BW, FW, EE, and ASH (P<0.05 or P<0.01) relative to purebred Saudi rabbits. Estimates were slightly greater by 1.8 to 10.9% for slaughter and edible carcass traits, by 3.3 to 10.5% for non-edible carcass traits, by 6.0 to 19.0% for carcass composition traits, and by 4.2 to 31.7% for meat quality traits compared with purebred V-line. **Saudi 3** rabbits, for the majority of traits were superior relative to purebred **S** or **V** line rabbits with the estimates of differences ranging from 9.4 to 23.0% for slaughter weight and edible carcass traits, 13.2 to 23.1% for non-edible carcass traits, 7.4 to 27.1% for carcass composition~~s~~ traits and 1.1 to 32.1% for meat quality traits relative to purebred Saudi rabbits. The corresponding percentages ranged from 1.8 to 7.3%, 4.9 to 11.4%, 2.8 to 21.6%, and 3.4 to 26.9% compared with purebred V-line rabbits. Analyses of crossbreeding experiments carried out in the Arabian countries (*e.g.* Afifi et al., 1994; El-Deghadi, 2005) showed much less heterosis in carcass traits than for the two synthetic lines developed here.

Heritability estimates

Heritability estimates for edible and non-edible carcass, lean composition and meat quality traits were mostly moderate (Table 7). The estimates ranged from 0.15 to 0.22 for slaughter and edible carcass traits, from 0.12 to 0.22 for non-edible carcass traits, from 0.14 to 0.20 for carcass composition~~s~~ traits, and from 0.12 to 0.36 for meat quality traits. Heritabilities estimated by Ayyat et al. (1994) for non-edible carcass traits for NZW rabbits raised in Egypt were low to moderate. In Brazil, Ferraz and Eler (1996) reported moderate estimates of heritability for carcass weight and carcass yield of 0.178 and 0.152 for the Californian breed and 0.152 and 0.000 for New Zealand White rabbits, respectively. Heritability estimated by Lukefahr *et al.* (1996) in USA for carcass yield was 0.37 in rabbits selected for 70-day body weight. Lukefahr *et al.* (1996) in USA reported quite different estimates for the loin primal yield cut (0.25) and lean-to-bone ratio of loin primal cut (0.35). From the genetic point of view, moderate improvements were achieved in carcass traits through selection of animals in this project using breeding values estimated with the animal model. Shortening the generation interval to 10 months also accelerated genetic improvement obtained in the different genetic groups.

Common litter effects

Variance due to common litter effects for carcass traits, carcass composition traits and meat quality were moderate to high and were always higher than the respective heritabilities (Table 7). The estimates ranged from 0.31 to 0.37 for slaughter and edible carcass traits, 0.29 to 0.39 for non-edible carcass traits, 0.15 to 0.29 for composition traits, and 0.17 to 0.23 for meat quality traits. Common litter effects appeared to have strong effects on growth even up to slaughtering time. Ferraz *et al.* (1992) reported common environmental effects to be consistently more important than direct genetic effects for several traits studied, but Lukefahr *et al*. (1996) indicated that for each carcass trait investigated, the magnitudes of variance components for direct genetic and common environmental effects were similar. However, the estimates for carcass and meat quality traits from this study were generally smaller than estimates available in the literature (e.g. Ferraz *et al.,* 1992; Lukefahr *et al*., 1996).

Conclusion

Rabbits of the two synthetic lines developed in the present study were considerably superior for carcass traits, carcass composition traits and meat quality traits comparable to purebred rabbits. The favorable estimates of superiority of the composite **Saudi 2** and **Saudi 3** lines suggest that producers and processors in hot climate countries could obtain economic benefits through using rabbits of these lines on a commercial scale.

Acknowledgments

This project is supported by a great grant (ARP: 18-62) from King Abdulaziz City for Science and Technology in Saudi Arabia. We are appreciated the scientific cooperation of Professor M. Baselga, Departamento de Ciencia Animal, Universidad Politecnica de Valencia, Camino de Vera 14, Apdo 22012, 46071, Spain who supplying us with V-line rabbits and for his fruitful discussion.

REFERENCES

Afifi, E.A., Khalil, M.H., Khadr, A.F. and Youssef, Y.M.K. 1994. Heterosis, maternal and direct effects for post weaning growth traits and carcass performance in rabbit crosses. *Journal of Animal Breeding and Genetics,* 111: 138-147.

A.O.A.C 1990. Official methods of analysis of the Association of Official Agricultural Chemists. Washington DC.

Ayyat, M.S., Anous, M.R. and Sadek, M.H. 1994. Genetic parameters for meat production in rabbits. 1. Non carcass components. *World Rabbit Science,* 2(3): 93-99.

Blasco, A.; Ouhayoun, J.; and Masoero, G. 1993. Harmonization of criteria and terminology in rabbit meat research. World Rabbit Sci., 1(1):3-10.

Bianospino, E., Moura, A.S.A.M.T., Wechsler, F.S., Fernandes, S. and Roca, R.O. 2004a. Carcass and meat quality of straightbred and crossbred rabbits. 8th World Rabbit Congress, 7-10 September 2004, Puebla, Mexico, pp 1354-1359.

Bianospino, E., Wechsler, F.S., Moura, A.S.A.M.T. and Fernandes, S. 2004b. Growth traits and dressing percentage of straightbred and crossbred rabbits. 8th World Rabbit Congress, 7-10 September 2004, Puebla, Mexico, pp. 1360-1365.

Boldmann, K. G.; Kriese, L. A.; Van Tassell, C. P.; Kachman, S. D. 1995. A manual for use of MTDFREML. A set programs to obtain estimates of variances and covariance [DRAFT]. U.S. Department of Agriculture, Agricultural Research Service, USA.

El-Deghady, Amira S. 2005. Genetic evaluation for some productive traits in rabbits. Ph.D. Thesis, Faculty of Agriculture, Banha University, Egypt.

Estany, J., Baselga, M., Blasco, A. and Camacho, J. 1989. Mixed model methodology for the estimation of genetic response to selection in litter size of rabbits. *Livestock Production Science*, 21:67-76.

Feki, S., Gómez, E.A., Baselga, M. and Cifre, J. 1994. Differences in carcass composition in three rabbit lines selected for different traits. In: Proceedings of 5th World Genetic Congress Applied to Livestock Production. Guelph, Canada.

Ferraz, J.B.S. and Eler, J.P. 1996. Comparison of animal models for estimation of (co)variance components and genetic parameters of reproductive, growth and slaughter traits of Californian and New Zealand rabbits raised under tropical conditions. Proceedings of 6th World Rabbit Congress, Vol 2: 279-284. Toulouse, France.

Ferraz, J. B. S.; Johnson, R. K.; Van Vleck, L. D. 1992. Estimation of genetic trends and genetic parameters for reproductive and growth traits of rabbits raised in subtropics with animal model. J. Applied Rabbit Research, **15**:131-142.

Garcia, M.L.; Blumetto, O.; Capra, G.; Vicente, J. S. and Baselga, M. 2000a. Vitrified embryo of two selected Spanish rabbit lines to Uruguay. In: *Proceedings 7th World Rabbit Congress*, Valencia, Spain, 4-7 July 2000, World Rabbit Science, 8 Supp. 1: 139-142.

Garcia, M. L.; Baselga, M.; Lavara, R; Lavara, F. and Vicente, J. S. 2000b. Reproductive characters in crossbreeding among three maternal lines of rabbits. *7th World Rabbit Congress*, Valencia, Spain, Volume A: 397-402.

Gomez, E.A., Baselga, M., Rafel, O., and Ramon, J. 1998. Comparison of carcass characteristics in five strains of meat rabbit selected on different traits. *Livestock Production Science*, 55: 53-64.

Khalil, M.H., Mehaia, M.A., Al-Hodiman, A.H. and Al-Sobayil, K.A. 2004. Genetic analysis for milk yield and components and milk conversion ratio in crossing of Saudi rabbits with V-line. In: Proceedings of the 8th World Rabbit Congress, 7-10 September 2004, Puebla, Mexico, pp 82-89.

Khalil, M., García, M.L., Al-Sobayil, K.A., Al-Homidan, A.H. and Baselga, M. 2005. Genetic evaluation of crossbreeding project involving Saudi rabbits and Spanish V-line to synthesize new maternal lines in Saudi Arabia. I. Pre-weaning litter and lactation traits and feeding parameters. In: Proceedings of the 4th International Conference on Rabbit Production in Hot Climates. 24-27 February 2005. Sharm El-Shiekh. Egypt.

Khalil, M.H., Al-Sobayil, K.A., Al-Saef, A.M., García, M.L.and Baselga, M. 2007. Genetic evaluation for semen characteristics and libido in a crossbreeding project involving Saudi and Spanish V-line rabbits. Paper No. ANIMAL-06-10132R1 accepted for publication International Journal of Animal Bioscience, In Press.

Lobera, J., Ruiz, F., Ferrández, F., Baselga, M. and Torres, C. 2000. Terminal sire and production of meat rabbit. In: Proceedings of *7th World Rabbit Congress,* 4-7 July 2000, Valencia, Spain, Vol A: 449-455. Valencia, Spain.

Lukefahr, S., Hohenboken, W.D., Cheeke, P.R., Patton, N.M. and Kennick, W.H. 1982. Carcass and meat characteristics of Flemish Giant and New Zealand White purbred and terminal-cross rabbits. *J. Animal Sci*. 54:1169.

Lukefahr, S.D., Hohenboken, W.D., Cheeke, P.R. and Patton, N.M. 1983. Appraisal of nine genetic groups of rabbits for carcass and lean yield traits. *Journal of Animal Science,* 57(4): 93-109.

Lukefahr, S.D., Odi, H.B. and Atakora, J.K.A. 1996. Mass selection for 70 day body weight in rabbits. *Journal of Animal Science,* 74: 1481-1489.

Masoero, G., Ubertalle, A., Mazzocco, P. and Battaglini, L.M. 1985. Terminal crossing of New Zealand White and Californian Rabbits. (2) Characteristics on the live animal. *Annalidell Istituto Sperimentale per la Zootecnia,* 18(2): 93-109. (Animal Breeding Abstract, 55, No. 1264).

Masoero, G., Napolitano, F, Bergoglio, G, Riccioni, L. and Zoccarato, I. 1992. Crossbreeding experiment of New Zealand White females with White Giant, Pure and synthetic and stabilized strains in conventional or fasted preslaughter condition. *J. Applied Rabbit Research* 15:166-173.

Metzger Sz., Odermatt, M., Szendro Zs., Mohaupt M., Romvari R., Makai A., Biro-Nemeth E., Radnai I. and Sipos L. 2004a. Comparison of carcass traits and meat quality of Hyplus hybrid, purebred Pannon White rabbits and their crossbreds. 8th World Rabbit Congress, 7-10 September 2004, Puebla, Mexico, pp 1422-1428.

Metzger Sz., Odermatt, M., Szendro Zs., Mohaupt M., Romvari R., Makai A., Biro-Nemeth E., Radnai I. and Sipos L. 2004b. Examination on the carcass traits of different rabbit genotypes. 8th World Rabbit Congress, 7-10 September 2004, Puebla, Mexico, pp 1429-1434.

Ozimba, C.F. and Lukefahr, S.D. 1991. Evaluation of purebred and crossbred rabbits for carcass merit. *Journal of Animal Science*, 69: 2371-2378.

Piles, M., Blasco, A. and Pla, M. 2000. The effect of selection for growth rate on carcass composition and meat characteristics of rabbits. *Meat Science,* 54: 347-355.

Pla, M., Hernández, P. and Blasco, A. 1996. Carcass composition and meat characteristics of two rabbits breeds of different degrees of maturity. *Meat Science*, 44(1-2): 75-83.

Pla, M., Guerrero, L., Guardia, D., Oliver, M.A. and Blasco, A. 1998. Carcass characteristics and meat quality of rabbit lines selected for different objectives: I. Between lines comparison. *Livestock Production Science,* 54: 115-123.

Sánchez, J.P., Baselga, M., Silvestre, M.A. and Sahuquillo, J. 2004. Direct and correlated responses to selection for daily gain in rabbits. Proceedings of 8th World Rabbit Congress, Puebla, México, pp. 169-174.

Table 1. Genetic groups of the rabbits slaughtered and their sires and dams and numbers slaughtered at 12 weeks of age for each genetic group						
Ordinal number	Rabbit genetic group	Sire genetic group	Dam genetic group	Grand-dam group	Rabbits slaughtered	Rabbits chemically analyzed
1	V-line (V)	V-Line	V-Line	V	276	234
2	Saudi (S)	Saudi (S)	Saudi (S)	S	275	232
3	½V½S	V	S	S	223	203
4	½S½V	S	V	V	260	216
5	¾V¼S	V	½S½V	V	141	129
6	¾S¼V	S	½V½S	S	204	158
7	$(½V½S)^2$	½V½S	½V½S	S	113	111
8	$(½S½V)^2$	½S½V	½S½V	V	157	145
9	$(¾V¼S)^2$	¾V¼S	¾V¼S	½S½V	173	155
10	$(¾S¼V)^2$	¾S¼V	¾S¼V	½V½S	202	198
11	$(¾V¼S)^2$	$(¾V¼S)^2$	$(¾V¼S)^2$	¾V¼S	197	189
12	$(¾S¼V)^2$	$(¾S¼V)^2$	$(¾S¼V)^2$	¾S¼V	145	137
13	**Saudi 2**	$(¾V¼S)^2$	$(¾V¼S)^2$	$(¾V¼S)^2$	123	122
14	**Saudi 3**	$(¾S¼V)^2$	$(¾S¼V)^2$	$(¾S¼V)^2$	281	224
Total					**2770**	**2453**

Table 2: Least-square means and their standard errors (±SE) for pre-slaughter weight and edible carcass traits for the genetic groups

Genetic group	PSW, g		HCW, g		DP, %		OW, g	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
V-line (V)	2486	29	1423	19	57	0.2	110	2.0
Saudi (S)	2289	30	1223	19	53	0.2	90	2.0
½V½S	2406	29	1334	19	55	0.2	96	2.0
½S½V	2452	30	1369	20	55	0.2	98	2.0
¾V¼S	2456	36	1362	24	55	0.3	96	2.5
¾S¼V	2472	37	1389	24	56	0.3	95	2.4
$(½V½S)^2$	2462	35	1357	23	55	0.3	95	2.4
$(½S½V)^2$	2402	37	1385	25	57	0.3	95	2.6
$(¾V¼S)^2$	2469	40	1360	26	54	0.3	96	2.8
$(¾S¼V)^2$	2501	28	1474	18	54	0.2	100	1.9
$(¾V¼S)^2$	2431	40	1429	27	54	0.3	97	2.8
$(¾S¼V)^2$	2540	35	1490	23	54	0.3	102	2.4
Saudi 2	2589	68	1474	45	56	0.6	98	4.7
Saudi 3	2623	43	1504	29	58	0.4	102	3.1
Significance	P<0.001		P<0.001		P<0.001		P<0.05	

PSW= Pre-slaughter weight; HCW= Hot carcass weight; DP= Dressing percent; OW= Offal weight.
*= P<0.05; *** = P<0.001.

Table 3: Least-square means and their standard errors (±SE) for non-edible carcass traits for the genetic groups

Genetic group	HW, g		FURW, g		LW, g		VW, g	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
V-line (V)	225	2.4	239	3.9	105	1.3	391	6.1
Saudi (S)	207	2.5	215	4.0	95	1.4	369	6.2
½V½S	218	2.4	227	3.9	100	1.3	388	6.1
½S½V	224	2.5	239	4.0	100	1.4	372	6.2
¾V¼S	222	3.0	232	4.9	110	1.6	401	7.6
¾S¼V	223	3.1	236	4.8	104	1.7	390	7.5
$(½V½S)^2$	226	2.9	232	4.8	108	1.6	405	7.4
$(½S½V)^2$	219	3.1	228	5.1	104	1.7	411	7.9
$(¾V¼S)^2$	224	3.3	235	5.5	107	1.8	409	8.5
$(¾S¼V)^2$	224	2.3	241	3.8	106	1.3	415	5.9
$(¾V¼S)^2$	221	3.4	233	5.6	104	1.8	409	8.6
$(¾S¼V)^2$	225	2.9	244	4.8	106	1.6	415	7.4
Saudi 2	234	5.6	247	9.4	116	3.1	409	14.4
Saudi 3	236	3.6	246	6.1	117	2.0	418	9.2
Significance	P<0.001		P<0.001		P<0.001		P<0.001	

HW= Head weight; FURW= Fur weight; LW= Lung weight; VW= Viscera weight.
*** = P<0.001.

Table 4: Least-square means and their standard errors (±SE) for carcass composition traits for the genetic groups								
Genetic group	MW, g		BW, g		FW, g		MBR	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
V-line (V)	1037	14	281	5.2	24.5	1.48	3.84	0.07
Saudi (S)	919	14	253	5.3	25.6	1.50	4.35	0.07
½V½S	1000	14	271	5.2	26.9	1.47	3.85	0.07
½S½V	1030	14	268	5.3	28.2	1.50	3.96	0.07
¾V¼S	1044	18	259	6.8	26.1	1.90	4.12	0.09
¾S¼V	1058	17	259	6.2	27.0	1.77	4.12	0.08
$(½V½S)^2$	1046	17	265	6.7	25.9	1.87	4.05	0.09
$(½S½V)^2$	1047	19	277	7.1	22.5	1.98	3.88	0.10
$(¾V¼S)^2$	1049	20	273	7.7	27.6	2.15	3.94	0.11
$(¾S¼V)^2$	1068	14	272	5.1	25.8	1.44	4.08	0.07
$(¾V¼S)^2$	1031	20	266	7.8	25.7	2.18	3.96	0.11
$(¾S¼V)^2$	1070	17	268	6.5	30.0	1.83	4.20	0.09
Saudi 2	1050	34	298	13.2	27.7	3.67	4.57	0.19
Saudi 3	1068	22	289	8.4	28.0	2.34	4.67	0.12
Significance	P<0.001		P<0.01		NS		P<0.01	
MW= Meat weight; BW= Bone weight; FW= Fat weight; MBR= Meat to bone ratio. NS= P>0.05; ** = P<0.01; *** = P<0.001.								

Table 5: Least-square means and their standard errors (±SE) for chemical composition traits of the lean in the genetic groups										
Genetic group	MP		DM		CP		EE		ASH	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
V-line (V)	62.4	2.34	24.1	0.95	61.6	3.0	14.5	0.76	8.2	0.39
Saudi (S)	65.9	2.36	26.9	0.95	65.6	3.0	15.6	0.77	9.0	0.40
½V½S	60.1	2.30	23.7	0.93	61.7	2.9	11.7	0.76	6.6	0.39
½S½V	63.5	2.35	25.5	0.95	50.8	3.0	12.7	0.77	7.6	0.41
¾V¼S	55.3	3.05	22.6	1.24	52.5	3.9	8.4	0.99	8.9	0.47
¾S¼V	59.9	2.74	24.1	1.10	58.9	3.5	11.5	0.90	7.5	0.51
$(½V½S)^2$	60.5	3.03	25.1	1.24	53.7	3.9	9.2	0.99	10.4	0.45
$(½S½V)^2$	62.0	3.21	24.9	1.31	52.9	4.1	9.9	1.04	12.0	0.48
$(¾V¼S)^2$	60.5	3.50	25.2	1.43	62.2	4.5	9.7	1.14	11.0	0.51
$(¾S¼V)^2$	60.6	2.31	25.9	0.94	60.0	2.9	9.4	0.75	11.3	0.37
$(¾V¼S)^2$	60.4	3.55	25.3	1.45	66.0	4.5	11.0	1.15	10.8	0.52
$(¾S¼V)^2$	59.4	2.96	26.7	1.21	65.3	3.8	9.8	0.96	10.5	0.46
Saudi 2	65.0	6.02	26.7	2.47	68.2	7.7	11.2	1.95	10.8	0.85
Saudi 3	60.3	3.83	27.2	1.57	65.5	4.9	10.6	1.24	10.3	0.55
Significance	NS		NS		P<0.05		P<0.001		P<0.001	

MP= Moisture in lean; DM= Dry matter in lean; CP= Crude protein in lean; EE= Ether extract in lean; ASH= Ash in lean; NS= P>0.05; *= P<0.05; *** = P<0.001.

Table 6. Improvement (%) in synthetic lines relative to purebreds for carcass traits and meat quality

Trait	Improvement (%) in **Saudi 2** relative to		Improvement (%) in **Saudi 3** relative to	
	S	**V**	**S**	**V**
PSW	13.1**	4.1 ns	14.6**	5.5 ns
Edible carcass traits:				
HCW	20.5**	3.6 ns	23.0**	5.7 ns
DP	5.7 ns	-1.8 ns	9.4*	1.8 ns
OW	8.9*	-10.9**	13.3**	-7.3 ns
Non-edible carcass traits:				
HW	13.0**	4.0 ns	14.0**	4.9 ns
FURW	14.9**	3.3 ns	14.4**	4.9 ns
LW	22.2**	10.5**	23.1**	11.4**
VW	10.8**	4.6 ns	13.2**	6.9 ns
Tissues composition in the carcass:				
MW	25.7**	10.9**	27.1**	12.6**
BW	17.8**	6.0 ns	14.2**	2.8 ns
FW	8.2*	13.1**	9.4*	14.3**
MBR	5.1 ns	19.0**	7.4 ns	21.6**
Meat quality traits, DM basis (%):				
MP	-1.4 ns	4.2 ns	-8.5*	-3.4 ns
DM	-0.7 ns	10.8**	1.1 ns	12.9*
CP	4.0 ns	10.7**	-0.2 ns	6.3 ns
EE	-28.2**	-22.7**	-32.1**	-26.9**
Ash	20.0**	31.7**	14.4**	25.6**

Orthogonal comparisons were used to test for significance using the Student's t-test.
NS= P>0.05; *= P<0.05; ** = P<0.01.

Table 7: Estimates of the proportion of the phenotypic variance due to additive genetic effects (*h^2*) and to common litter effects (c^2) and to random error effects (e^2) with standard errors (±SE) for carcass and meat quality traits

Trait	h^2±SE	c^2±SE	e^2±SE
PSW	0.15±0.060	0.37±0.035	0.48±0.044
Edible carcass traits:			
HCW	0.22±0.069	0.32±0.036	0.46±0.049
DP	0.17±0.078	0.35±0.036	0.48±0.055
OW	0.17±0.069	0.31±0.037	0.52±0.049
Non-edible carcass traits:			
HW	0.22±0.068	0.34±0.037	0.44±0.048
FURW	0.12±0.060	0.31±0.034	0.57±0.045
LW	0.13±0.051	0.39±0.033	0.48±0.038
VW	0.22±0.071	0.29±0.037	0.49±0.036
Carcass composition traits:			
MW	0.17±0.064	0.29±0.035	0.53±0.047
BW	0.19±0.066	0.21±0.033	0.60±0.049
FW	0.14±0.063	0.26±0.034	0.60±0.047
MBR	0.20±0.067	0.15±0.032	0.66±0.049
Meat quality traits, DM basis (%):			
MP	0.31±0.081	0.21±0.039	0.49±0.058
DM	0.36±0.084	0.21±0.040	0.43±0.059
CP	0.25±0.084	0.21±0.041	0.54±0.061
EE	0.12±0.070	0.23±0.037	0.65±0.052
ASH	0.13±0.029	0.17±0.025	0.70±0.012