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GENETIC ANALYSIS OF SLAUGHTER AND CARCASS QUALITY TRAITS IN CROSSBRED RABBITS COMING FROM A DIALLEL CROSS OF FOUR MATERNAL LINES

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Abstract: An experiment was carried out to estimate the genetic group effects and the crossbreeding genetic parameters of slaughter and carcass traits using data on the rabbits that were progeny of does coming from a full diallel cross between 4 maternal lines (A, V, H and LP) mated to bucks of the paternal line R. The rabbits of the 16 genetic groups, corresponding to the type of does of the diallel cross, were distributed in 4 Spanish farms and 1 genetic group (V line) was present in all farms in order to connect records among them and to be used as reference group. Crossbreeding parameters were estimated according to Dickerson's model. 1896 rabbits were measured for slaughter traits and 950 for carcass traits. The A and LP lines had the lowest values for dressing percentage (–1.71 and –1.98 compared with H line and –1.49 and –1.75 with the V line, respectively). The A line was the heaviest for commercial carcass weight. No relevant differences were observed between the crossbred groups for all traits. Regarding the reciprocal effects, there were significant differences in favour of A line as sire line in the crossbred AV. Regarding the combination of direct and maternal effects, the A line showed significantly higher values for cold carcass weight (133 g., 71 g. and 142 g. compared to the H, LP and V lines). For the same parameter the H line showed significantly higher averages on dressing percentages than A and LP lines, 1.44 and 2.13%, respectively. Line A also showed, in general, better direct-maternal effects than the V line. Grand-maternal effects were less important than direct-maternal ones. The estimates of maternal heterosis were, in general, negative, which could be a consequence of the positive heterosis for litter size. However, despite this relationship between growth and litter traits, it has not been common to find negative maternal heterosis in growth traits. A diminution of dressing percentage was detected in some crossbreds (AL and LV) and care must be taken if these types are used.

Key Words: crossbreeding parameters, diallel cross, slaughter traits, carcass traits, maternal lines, rabbits.

INTRODUCTION

In general, meat production in rabbits is based on a 3-way crossbreeding scheme that needs maternal and paternal lines. The selection criteria for maternal lines are litter size at birth or at weaning (Rochambeau *et al.*, 1994, Garreau *et al.*, 2004), while the paternal lines are selected for growth traits (Baselga, 2004). The selection for growth traits has made it necessary to shorten the growing period, as carcass weight is fixed by the market, so the degree of maturity of rabbits is lower (Pascual, 2007). At present, the slaughterhouses are tending to pay incentives for the dressing percentage when the decrease in the degree of maturity causes a reduction of this trait (Parigi-Bini *et al.*, 1992; Dalle-Zotte and Ouhayoun, 1995; Lebas *et al.*, 2001).

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Nowadays, 80% of the marketing of rabbit meat in Spain is based on whole carcass (Montero, 2011) but it is necessary to offer new products (e.g. cut parts) in order to expand production (Dalle Zotte, 2002). Carcass quality research is increasing in importance as the consumer demands leaner, attractive and implicitly wholesome carcasses. Fortunately, the commercial rabbit carcass is quite lean and does not present serious qualitative problems linked to anomalies of muscle biology or to the pre- and post-slaughter handling, compared to other species such as pig (Ouhayoun, 1992). Carcass quality can be also defined as the proportion of cut parts such as loin, hind and fore part (Larzul and Gondret, 2005). Another criterion defining carcass quality is the meat/bone ratio of the carcass, which can be fairly well predicted by the hind leg meat/bone ratio (Blasco *et al.*, 1992).

The objective of this work was to estimate differences and crossbreeding parameters for slaughter traits and carcass quality of rabbits, whose dams come from a full diallel-cross among four maternal lines and the sires from a paternal line; all the lines came from a large Spanish genetic improvement programme.

MATERIAL AND METHODS

Animals

The present study involved animals whose dams came from a full diallel cross among 4 maternal lines (A, V, H and LP) and their sires were from a paternal line (R). The maternal genetic groups involved in the experiment were 4 pure lines (AA, VV, HH and LL) and 12 single crosses: AV, VA, AH, HA, AL, LA, VH, HV, VL, LV, HL and LH. The first letter of the genetic group name corresponds to the sire line and the second one to the dam line name. L is used to identify the LP line as sire or dam of a genetic group. The animals used for this study were a sample of the animals used by Mínguez *et al.* (2015).

Crossbreeding Design and Management

The study was carried out in 4 different farms, located in Altura (Castellón, Spain), Rioseco de Tapia (León, Spain), Valencia (Spain) and Sant Carles de la Ràpita (Tarragona, Spain). In each farm, the same experimental design was performed. The distribution of the does in the farms was described by Mínguez *et al.* (2015). The genetic group VV was present in all farms, allowing data connection across farms, but as this was the only genetic type in all the farms, no interaction between farm and genetic type could be considered.

Twenty five females from each genetic group in the different farms were inseminated by bucks from the R line to ensure a sufficient number of young rabbits at weaning (at 28 d of age). At weaning, 120 young rabbits from each genetic group were randomly sampled, avoiding whole litters. The young rabbits were individually identified by a number tattooed on the ear and placed into collective cages until marketing at 63 d of age. For all farms, young rabbits were housed in commercial wire cages (80×51 cm) in a flat deck system, equipped with 1 frontal feeder and 1 nipple drinker. The maximum number of animals was 8 in each cage. These dimensions were enough to allow free access to food and water for all the animals. Steps were taken to avoid all animals in the same cage belonging to the same litter, but they always belonged to the same genetic group. During post-weaning period, rabbits were fed *ad libitum* on a standard commercial pellet diet and fresh water. The feed used at each farm for the experimental rabbits was the one used at the fattening time for all the rabbits on the farm. Its effect was included in the farm effect, which did not affect the comparisons because all of them were within farm comparisons. The whole fattening period lasted 5 wk in all the farms. In the farm of Altura it took place from February 1st 2011 to March 8th 2011; in Rioseco de Tapia from May 9th 2011 to June 13th 2011; in Universitat Politècnica de València (UPV) from February 21st 2012 to March 27th 2012, and in San Carles de la Ràpita from April 24th 2012 to May 29th 2012.

No serious health problems were observed throughout the experiment, but the mortality rate (14%) was higher than expected on a commercial farm; this mortality was unequal across genetic groups, thus the distribution of animals by genetic group was unbalanced. The observed high mortality could be consequence of the intense weekly manipulations of young rabbits for data collection.

The rabbits were fasted of solids pellets for 24 h before slaughter. Transport of the rabbits to the slaughterhouse was in an adapted vehicle, authorised to perform the activity. The commercial slaughterhouse for animals from the farm at Altura was located in Gaibiel (Castellón, Spain). For the rest of the animals, the slaughter was conducted in the experimental slaughterhouse of the Animal Science Department of the Polytechnic University of Valencia (UPV). In all cases the journey was less than 12 h, including loading and unloading the animals. In loading the rabbits, the genetic groups were randomised (each box contained 1 animal from each genetic group) to avoid differences due to waiting times at the slaughterhouse. Spanish legal regulations (BOE-A-1995-3942) regarding slaughter shock to prevent animals from suffering were followed. In both slaughterhouses, an electrical shock with a voltage and frequency of 49 V and 179 Hz, respectively, and an approximately 2 seconds duration, was used. The electrical shock was also needed to preserve the safety of personnel, to ensure the correct evolution of muscle to meat and to immobilise the animal to facilitate the initiation of bleeding (Ouhayoun, 1988).

Data Recording and Statistical Model

All the slaughter and carcass traits studied follow the official criteria and terminology of the World Rabbit Scientific Association (Blasco *et al.*,1993). The slaughter traits studied were: Liveweight at 63 d (after fasting, LW63, g), commercial skin weight (CSkW, g), full gastrointestinal tract weight (FGTW, g), hot carcass weight (HCW, g), and dressing percentage (DP: HCW divided by LW63×100). These traits were measured at the slaughterhouse.

After slaughter, hot carcasses were chilled for 24 h at 4°C and carcass quality characteristics were measured at the meat laboratory of the Department of Animal Science of the UPV. The carcass colour in the CIELAB space (L^*, a^* and b^*) was recorded on loin surface, at the 4^{th} lumbar vertebra of the right side at 24 h post-mortem using a CR300 Minolta Chromameter. The commercial carcass weight was recorded (CCW, g) and carcasses were dissected and measured according to the World Rabbit Scientific Association norms. Head weight (HW, g), liver weight (LvW, g), whole thoracic viscera weight (lungs, thymus, oesophagus, heart, LHW, g) and kidneys weight (KiW, g) were recorded in these carcasses. All these parts were removed to obtain the reference carcass weight (RCW, g). Reference carcass contained only meat, fat, and bone. Scapular (SFaW, g) and perirenal fat (PFaW, g) were excised from the carcass and were weighed. The technological joints measured were: fore leg weight (FLW, g), thoracic cage weight (without the insertion muscles of fore legs, TW, g), loin weight (LW, g) and hind leg weight (HLW, g). From the hind part of the carcass, the left leg was dissected to separate bone from edible meat to calculate meat bone ratio (M/B).

A total of 1896 carcasses were used to measure the slaughter traits and a sample of 950 carcasses were used in the meat laboratory (50 carcasses for each genetic group and farm) for measuring carcasses quality traits, with the exception of M/B for which a subsample of 475 carcasses (25 left leg for each genetic group and farm) was recorded.

The model used in the analysis was:

$$Y_{jkl}=GG_j+F_k+S_l+e_{jkl}$$

Where Y_{jkl} is a record of the trait; GG_j is the effect of genetic group (16 levels); F_k is the effect of the farm (4 levels); S_l is the effect of the sex and e_{jkl} is the residual effect.

Estimates of the differences between all the genetics groups and VV animals were obtained by generalised least squares, using the program blupf90 (Misztal *et al.*, 2002), in addition to the estimates, the error (co)variance matrix between these estimates were obtained. The residual variances required to solve the models were estimated in a previous REML step. Crossbreeding genetic parameters (direct, maternal and grand-maternal additive genetic effects, individual and maternal heterosis) were considered according to the model proposed by Dickerson (1969), to explain the expected means of the different genetic groups.

Given the genetic makeup of the experimental animals there were 5 different types of genetic parameters: direct additive genetic effects (G_i^D, i=A, V, H, L, R), maternal additive genetic effects (G_i^M, i=A, V, H, L), grand-maternal genetic effects ($G_i^{M'}$, i=A, V, H and L), individual heterosis (H_{Ri}^I, i=A, V, H, L) and maternal heterosis (H_{ij}^M, i≠j, i=A, V, H, L and j=A, V, H, L). These genetic parameters are not estimable individually, but their following functions are estimable:

a) Direct-maternal differences between lines, $G_{i-j}^I = \frac{1}{2}(G_i^D - G_j^D) + (G_i^M - G_j^M) + (H_{Ri}^I - H_{Rj}^I)$, i≠j, i=A, V, H, L and j=A, V, H, L. *b)* Grand-maternal differences between lines, $((G_{i-j}^{M'} = G_i^{M'} - G_j^{M'})$, i≠j, i=A, V, H, L and j=A, V, H, L. *c)* Maternal heterosis, previously defined.

Estimable functions of the crossbreeding parameters were obtained by adjusting by generalised least squares the estimates of the genetic group effects (as contrasts to the V line) to the coefficients described in Mínguez *et al.* (2015). In this generalised least squares procedure the error (co)variance matrix between the estimates of the genetic group effects was used as weighting matrix (Baselga *et al.*, 2003). Wald tests were performed to test for significance of both contrasts between genetic types and estimable functions of the crossbreeding genetic parameters.

RESULTS AND DISCUSSION

Descriptive Statistics

Summary statistics for all traits are shown in Table 1. For slaughter traits, the mean for LW63 and HCW is within the range of commercial weights in Spain (2100 and 1200 g, respectively) (MAGRAMA, 2012). Pla (2008) studied animals from a three-way crossbreeding scheme (R×(A×V)) and slaughtered them also at 63 d in a nucleus farm. He obtained higher mean values for all measured traits; only DP (%) showed a lower mean than in our study. The higher values reported by Pla (2008) could be explained by the better environmental conditions provided to the UPV nucleus animals used in that study, compared to those provided in commercial farms, as in our study. For A, V and R lines as purebred, Hernández *et al.* (2006) and Zomeño *et al.* (2010) obtained general means for these traits similar to ours. Gómez *et al.* (1998) studied, at a fixed age of 60 d, some slaughter and carcass traits and the means they obtained were in the same magnitude than in our study; they considered purebred animals from the maternal lines Prat and V and from the paternal lines Caldes and R. Prat and V lines are selected for litter size at weaning (the V line was explained above), and Caldes and R line are selected for individual post-weaning daily weight gain. The similarities between our study, and the studies of Hernández *et al.* (2006) and Gómez *et al.* (1998) were expected because they

Table 1: Descriptive statistics for slaughter and carcass quality traits.

Trait	No	Mean	SD	Minimum	Maximum
LW63, (g)	1896	2144	234	1200	2880
CSkW, (g)	1896	232	35	110	385
FGTW, (g)	1896	404	51	280	630
HCW, (g)	1896	1250	154	650	1650
DP, (%)	1896	58	2	50	63
L*	950	56.81	2.5	47.43	63.87
a*	950	3.59	1.17	0.58	8.51
b*	950	–0.12	2.30	–7.9	5.74
CCW, (g)	950	1249	144	750	1638
HW, (g)	950	116	11	81	154
LvW, (g)	950	77	18	42	148
KiW, (g)	950	15	1	8	27
LHW, (g)	950	27	4	14	46
RCW, (g)	950	1013	130	563	1361
SFaW, (g)	950	7	2	1	16
PFaW, (g)	950	19	6	4	59
HLW, (g)	950	380	46	227	532
LW, (g)	950	317	49	109	463
FLW, (g)	950	174	25	94	248
TW, (g)	950	107	19	51	200
M/B	475	5.0	0.6	2.9	6.4

LW63:liveweight at 63 d after fasting. CSkW:commercial skin weight. FGTW: full gastrointestinal tract weight. HCW: hot carcass weight. DP: dressing percentage. L*: lightness of loin surface. a*: redness of loin surface. b*: yellowness of loin surface. CCW: commercial carcass weight. HW: head weight. LvW: liver weight. KiW: kidneys weight. LHW: thoracic viscera weight. RCW: reference carcasses weight. SFaW: scapular fat weight. PFaW: perirenal fat weight. HLW: hind leg weight. LW: loin weight. FLW: fore leg weight. TW: thoracic cage weight. M/B: meat to bone ratio. No: number of rabbits. SD: standard deviation.

used purebred animals and the overall average was the average between the paternal and maternal lines. We only obtained higher values than Hernández *et al.* (2006) and Zomeño *et al.* (2010) for SFaW and PFaW, this is because we used the line R as parent for all young rabbits and it has been shown (Hernández *et al.*, 2004) that the R line has higher dissectible fat than A and V lines. Piles *et al.* (2004) only used the paternal lines R and Caldes and their overall mean for LW63, CCW and DP were clearly superior to ours. The mean values obtained for meat colour in the *longissimus dorsi* surface were within the range of the bibliography consulted. The reported values for these traits were between 54.0 and 57.9 for L*, between 2.46 and 3.7 for a*; and between –1.03 and 2.84 for b* (Battaglini *et al.*, 1994; Xiccato *et al.*, 1994; Hernández *et al.*, 1997, 2004, 2006).

Differences between genetic groups

In Table 2, the contrasts between the dam effects of the lines for the studied traits can be observed. Differences in LW63 are economically important because the incomes of farmers are through LW63. A trend can be observed indicating that V line was the lightest and the LP line was the heaviest (no significant differences), and in another study involving a larger amount of LW63 records this trend was confirmed (Mínguez *et al.*, 2012), showing that at 63 d, the H and LP lines were the heaviest, followed by the A line, and the V line was the lightest. Hernández *et al.* (2006) for the contrast A-V obtained the same result. For CSkW, the A and LP lines were the heaviest with significant differences compared to the V line (the lightest one). This result is in agreement with Pla *et al.* (1995), who found that the skin of line A was heavier than the skin of line V.

For DP, lines A and LP showed the lowest values, with significant and relevant differences compared to lines H and V. It has to be noted that despite the low variability of the trait (s.d. equal to 2%), differences between lines of up to 1.98% were observed. The superiority observed for CSkW of the A and LP lines, which also showed the heaviest

Table 2: Contrasts (standard error) between the lines for slaughter and carcass quality traits.

Trait	A-H	A-LP	A-V	H-V	LP-H	LP-V
LW63, (g)	28(76)	–40(54)	53(54)	25(53)	68(77)	93(56)
CSkW, (g)	10(10)	3(7)	23(7)*	13(7)	6(10)	19(7)*
FGTW, (g)	15(15)	–8(10)	10(10)	–5(10)	23(15)	18(11)
HCW, (g)	–25(48)	–19(35)	–5(35)	19(34)	–6(49)	13(35)
DP, (%)	–1.71(0.60)*	0.24(0.43)	–1.49(0.43)*	0.22(0.42)	–1.98(0.43)*	–1.75(0.44)*
L*	–0.09(0.59)	–0.38(0.45)	–0.27(0.43)	–0.18(0.42)	0.30(0.56)	0.12(0.41)
a*	–0.03(0.25)	0.13(0.18)	–0.53(0.18)*	–0.51(0.18)*	–0.15(0.36)	–0.66(0.18)*
b*	–0.07(0.48)	–0.26(0.35)	–1.08(0.35)*	–1.00(0.33)*	0.19(0.48)	–0.82(0.34)*
CCW, (g)	83(38)*	22(27)	60(27)*	–22(26)	61(37)	38(27)
HW, (g)	9(3)*	3(2)	8(2)*	–1(2)	5(3)	4(2)*
LvW, (g)	–5(4)	1(3)	1(3)	7(3)*	–6(4)	1(3)
KiW, (g)	1(0.51)*	1(0.37)	1(0.37)*	0(0.35)	1(0.51)	0(0.36)
LHW, (g)	1(1.00)	–1(0.86)	0(0.85)	–1(0.82)	1(1.00)	0(0.85)
RCW, (g)	72(32)*	17(23)	49(23)*	–23(22)	55(32)	32(23)
SFaW, (g)	–1(0.65)	0(0.47)	0(0.46)	1(0.45)*	–1(0.64)	0(0.46)
PFaW, (g)	1(2)	3(1)*	1(1)	0(1)	–2(2)	–1(1)
HLW, (g)	36(11)*	0(8)	16(8)*	–20(8)*	36(11)*	15(8)
LW, (g)	14(12)	5(8)	15(8)	2(8)	8(12)	9(8)
FLW, (g)	9(6)	9(4)*	5(4)	–3(4)	0(6)	–3(4)
TW, (g)	14(5)*	0(3)	7(3)*	–7(3)*	14(5)*	8(3)*
M/B	0.30(0.22)	0.10(0.15)	0.36(0.15)*	0.06(0.15)	0.19(0.22)	0.25(0.15)

LW63: liveweight at 63 d after fasting. CSkW: commercial skin weight. FGTW: full gastrointestinal tract weight. HCW: hot carcass weight. DP: dressing percentage. L*: lightness of loin surface. a*: redness of loin surface. b*: yellowness of loin surface. CCW: commercial carcass weight. HW: head weight. LvW: liver weight. KiW: kidneys weight. LHW: thoracic viscera weight. RCW: reference carcasses weight. SFaW: scapular fat weight. PFaW: perirenal fat weight. HLW: hind leg weight. LW: loin weight. FLW: fore leg weight. TW: thoracic cage weight. M/B: meat to bone ratio.

*P<0.05 (significant difference at α=0.05).

LW63, meant that compared to HCW the observed differences between lines were reduced or changed the sign of the differences in LW63.

This reduction produced the contrasts A-V and LP-V, regarding DP to be of opposite sign to those for LW63. It was observed that, when the contrasts in CSkW had the same sign as those for LW63, significant differences in DP were observed, i.e. the differences between LW63 and HCW were higher. Note that the significant differences in DP were between the heaviest and the lightest lines for LW63 and CSkW (contrasts A-H, A-V, LP-H and LP-V). The differences in favour of A and LP lines for FGTW, as happened with the CSkW, may also contribute to reduce the DP of these lines, but the differences for this trait were less important. This agrees with the results of Ouyed *et al.* (2011) for Californian, American Chinchilla and New-Zealand White breeds, as they observed that the rabbits with the lowest LW63 also had the highest DP. They explained this result by the lower proportion of skin found in these rabbits.

Most rabbit meat is usually marketed as whole carcasses, but nowadays retail cuts are increasing in importance. Thus, carcass and muscle colour of the cuts are traits increasing in relevance, as they might affect consumer acceptance and purchasing decisions, and colour parameters are directly related to the appearance of the product. Rabbit meat is paler than pork or beef, with a low redness index (Hernández *et al.*, 1997). No significant differences were observed for L*, but for a* and b*, the V line showed the lowest values (with significant differences with the other lines). These results are in agreement with Hernández *et al.* (2006), who obtained small differences for L* between lines A and V, but rather relevant differences regarding a* and b*. Dalle Zotte and Ouhayoun (1998) also found differences in L*, a* and b* between different rabbit breeds. At present, consumers do not seem to have carcass colour preferences, but it would be convenient to survey changes during the selection programme (Hernández *et al.*, 2006).

For CCW the line A was the heaviest (with significant differences with H and V lines). Although the correlation between HCW and CCW is near one (Ogah *et al.*, 2012), the contrasts between the lines for HCW change the sign for CCW. This change between HCW and CCW can be a random consequence due to the fact that the animals measured in the laboratory were a sample of the animals used for measuring slaughter traits (50% approx.). For HW, the line A was the heaviest (significant differences with H and V lines) followed by the LP line (significant differences with V line) and the V line was the lightest. These results do not agree with results by Gómez *et al.* (1998) that used Prat, Caldes, R, V and A lines and did not find any differences between the lines for this trait. There were some significant differences for LvW (H-V in favour of the H line) and KiW (A-H and A-V in favour of the A line) but they are not economically relevant. For LHW no significant differences were found. These results are in agreement with Gómez *et al.* (1998), when comparing these traits for A and V lines. For reference carcass weight (RCW), the line A was the heaviest, with significant differences compared to H and V lines. The reference carcass weight (RCW), as defined by Varewyck and Bouquet (1982), contains only fat, meat and bone tissues. RCW and CCW are directly related, and RCW is equal to CCW plus HW, LvW, KiW and LHW. Because the differences between lines for HW, LvW, KiW and LHW are small, RCW contrasts were significant in the same cases as those for CCW. Rabbit carcasses have a small dissectible fat percentage (Pla *et al.*, 1996). Scapular and perirenal fat tissues are 2 of the main depots of the carcass and correspond to 65% of the carcass dissectible fat in the rabbit (Hernández *et al.*, 2006; Zomeño *et al.*, 2010). For the contrasts between lines for SFaW, the H line was the heaviest and the V line was the lightest, the difference between them being significant. Regarding PFaW, the A line was the heaviest and the LP line was the lightest, and the differences between them were also significant. Despite the significant differences and the fact that these differences represent up to 15% of the averages of the trait; the values of the contrasts cannot be said to be economically relevant because the total dissectible fat represents a very low percentage of the carcass (Pla *et al.*, 1996; Hernández *et al.*, 2006). In our study, the contrasts for these traits between A and V lines are in agreement with Hernández *et al.* (2006) and Zomeño *et al.* (2010) which showed that A line had more total dissectible fat than V line. In Gómez *et al.* (1998) no significant differences appeared in SFaW between A and V lines but for PFaW, unlike in our study, the V line was the one with more PFaW. It is necessary to take into account that Gómez *et al.* (1998) adjusted to a constant RCW.

The reference carcass was dissected into 4 parts: hind leg, loin, fore leg and thoracic cage. The first 3 are preferred because of their meat content, packaging facility or ease of cooking, being consequently the most expensive cuts of the rabbit carcass (Montero, 2011). Generally, line A was the heaviest for HLW, LW, FLW and TW, closely followed by the LP, and then the V and H lines. Significant differences were found for HLW in the contrasts A-H, H-V and LP-H, for FLW in the contrast A-LP and for TW in the contrasts A-H, A-V, LP-H and LP-V. Between the A and V lines, Gómez *et al.* (1998) showed that the A line was the lightest for FLW and non-significant differences for HLW, TW and LW were obtained. Hernández *et al.* (2006) studied differences between A and V lines in high priced cuts (loin and hind part) and these differences were very small. Brun (1993) showed that the increase of the litter size produces a reduction of the FLW. This is in disagreement with our results, as we observed that the lines with heaviest FLW were A and LP lines. The A line came from litters with the lowest liveborn numbers (BA, 10.13) and the lowest number of weaned rabbits (NW, 8.76), but the LP line had the higher prolificacy (12.30 BA and 10.56 NW). Despite some significant and relevant, in magnitude, differences of the retail cuts; rabbit carcass prices are currently established according to their retail cut, but in a near future perhaps it would be important take into account these traits to offer new products according to the new requirement of consumers and packaging systems. The meat/bone ratio in the hind leg provides a good prediction for meatiness referred to RCW (Varewyck and Bouquet, 1982; Blasco *et al.*, 1984; Hernández *et al.*, 1996). The A line showed the highest value of M/B ratio and the V line had the lowest value for this trait, this contrast reached a significant value. This find is in agreement with Hernández *et al.* (2006). In our results we can observe the association between CCW and RCW, and high values in the contrasts for carcass weights have also associated high values for M/B ratio.

In commercial farms, crossbred does are the most common type of females and, consequently, differences in slaughter and carcass traits in dam effects associated to the different types of crosses might have importance. As Mínguez *et al.* (2015) made for growth traits; we consider the different crossbred groups (the average of a cross and its reciprocal) compared to the V line (Table 3). In a global comparison of Tables 2 and 3, we observed that the contrasts between crossbreds and line V were smaller than between pure lines, i.e. less significant differences were

Table 3: Contrasts (standard error) between crossbred genetic groups[1] and V line for slaughter and carcass quality traits.

Trait	AH-VV	AL-VV	AV-VV	HV-VV	LH-VV	LV-VV	All-VV
LW63, (g)	13.93(37.50)	13.16(37.53)	–16.92(37.01)	–14.31(38.21)	12.67(36.90)	–1.58(37.03)	1.15(28.74)
CSkW, (g)	2.32(5.20)	9.96(5.20)	7.08(5.20)	4.65(5.34)	9.14(5.17)	8.11(5.18)	6.85(4.01)
FGTW, (g)	8.74(7.44)	12.68(7.43)	3.41(7.39)	–7.45(7.60)	2.44(7.35)	1.55(7.60)	3.55(5.70)
HCW, (g)	–0.14(24.00)	–9.65(24.00)	–21.31(23.80)	–7.28(24.40)	6.60(23.62)	–13.52(23.70)	–7.52(18.38)
DP, (%)	–0.44(0.31)	–0.82(0.30)*	–0.54(0.31)	0.07(0.31)	–0.11(0.31)	–0.62(0.30)*	–0.41(0.23)
L*	–0.13(0.31)	–0.54(0.31)	0.29(0.32)	–0.40(0.31)	–0.35(0.31)	–0.31(0.31)	–0.24(0.23)
a*	–0.44(0.13)*	–0.08(0.13)	–0.18(0.13)	–0.16(0.13)	–0.25(0.14)	–0.08(0.13)	–0.17(0.10)
b*	–0.56(0.24)*	–0.20(0.24)	–0.18(0.24)	–0.07(0.24)	–0.20(0.24)	–0.20(0.24)	–0.21(0.18)
CCW, (g)	8.06(19.47)	–18.30(19.32)	6.91(19.46)	–15.08(19.34)	31.46(19.37)	–17.91(19.32)	–0.80(14.67)
HW, (g)	0.87(1.53)	0.12(1.52)	–0.03(1.53)	0.17(1.53)	2.63(1.53)	–1.42(1.53)	0.39(1.16)
LvW, (g)	0.87(2.13)	–2.53(2.12)	1.02(2.15)	–3.59(2.14)	3.24(2.13)	1.36(2.13)	0.06(1.62)
KiW, (g)	–0.19(0.26)	–0.43(0.26)	–0.05(0.26)	–0.07(0.26)	0.21(0.0.26)	–0.07(0.26)	–0.10(0.20)
LHW, (g)	–2.16(0.61)*	–0.39(0.60)	0.22(0.61)	–0.84(0.60)	–2.01(0.60)*	–2.01(0.60)*	–1.19(0.46)*
RCW, (g)	11.07(16.60)	–11.56(16.52)	6.60(16.64)	–10.51(16.59)	26.99(16.60)	–16.63(16.56)	0.99(12.56)
SFaW, (g)	–0.36(0.33)	–0.30(0.34)	–0.20(0.33)	–0.03(0.33)	–0.24(0.34)	–0.15(0.34)	–0.03(0.25)
PFaW, (g)	0.98(0.96)	–2.06(0.95)*	0.01(0.96)	–0.67(0.96)	1.55(0.96)	0.21(0.96)	0.00(0.73)
HLW, (g)	–1.06(5.87)	–0.80(5.84)	1.49(5.88)	–6.90(5.86)	10.22(5.88)	–6.36(5.85)	–0.57(4.44)
LW, (g)	8.82 (6.16)	–4.12(6.16)	6.50(6.17)	1.24(6.15)	12.40(6.16)*	–2.13(6.15)	3.77(4.66)
FLW, (g)	–2.82(3.16)	5.04(3.15)	–1.91(3.17)	–0.72(3.16)	5.15(3.16)	–2.48(3.16)	–1.30(2.40)
TW, (g)	0.50(2.56)	–2.48(2.54)	2.91(2.56)	–2.15(2.56)	0.71(2.56)	–3.51(2.55)	–0.67(1.94)
M/B	–0.09(0.11)	–0.07(0.11)	–0.17(0.11)	–0.25(0.11)*	–0.23(0.11)	–0.21(0.11)	–0.17(0.08)*

[1]One cross and its reciprocal are considered together.

LW63: liveweight at 63 days after fasting. CSkW: commercial skin weight. FGTW: full gastrointestinal tract weight. HCW: hot carcass weight. DP: dressing percentage. L*: lightness of loin surface. a*: redness of loin surface. b*: yellowness of loin surface. CCW: commercial carcass weight. HW: head weight. LvW: liver weight. KiW: kidneys weight. LHW: Thoracic viscera weight. RCW: reference carcasses weight. SFaW: scapular fat weight. PFaW: perirenal fat weight. HLW: hind leg weight. LW: loin weight. FLW: fore leg weight. TW: thoracic cage weight. M/B: meat to bone ratio. L: LP line.

*P<0.05 (significant difference at α=0.05).

found for the crossbreds. For LW63 no significant differences were observed. Mínguez *et al.* (2015) studied the same animals for body weight at 63 d and, also, they did not observe significant differences. The small differences observed between Mínguez *et al.* (2015) and our study are probably due to the fact that LW63 was measured after a day of fasting. For CSkW, FGTW and HCW, non-significant differences were observed, however all crossbred groups shower higher CSkW than the V line. This is in agreement with the contrasts between lines (Table 2) that showed that the V line was the lightest for this trait. Regarding FGTW, in general crossbreds involving A line were the heaviest and only the crossbred HV was lighter than the V line. This agrees with the result commented before, these lines (H and V) were those having the lightest gastrointestinal tract. As pure lines, A and LP had the heaviest skin and full gastrointestinal tract, and the crossbreds involving these lines showed the worst DP (significant differences between AL-VV and LV-VV), some of these differences reaching important magnitudes, for example 0.8% for the contrast AL-VV, in favour of VV animals. For colour parameters, only significant differences appeared in the contrast AH-VV for a* and b*. This agrees with the significant differences observed between A and V, and between H and V lines (Table 2) for the same traits.

Non-significant differences were found for CCW, however, similarly to what happened when comparing lines (Table 2), regarding the association between HCW and CCW a negative association was observed; the explanation could be the same sampling effect argued for the lines comparison.

No significant differences were obtained for HW, LvW and KiW, and in this case the magnitudes of the contrasts were small.

For LHW, significant differences were observed between AH and VV, LH and VV, LV and VV and All and VV and despite these differences represent in some cases up to 8% of the averages of the trait; the values of the contrasts cannot be said to be economically relevant. Non-significant differences were obtained for RCW. For dissectible fat, a significant

Table 4: Contrasts (standard error) between reciprocal crosses for slaughter and carcass quality traits.

Trait	AH-HA	AL-LA	AV-VA	HV-VH	LH-HL	LV-VL
LW63, (g)	13(75)	–37(75)	46(74)	49(76)	–46(75)	–47(74)
CSkW, (g)	3(10)	–9(10)	–1(10)	9(10)	–4(10)	–2(10)
FGTW, (g)	2(15)	–6(15)	–13(15)	8(15)	–4(15)	–16(15)
HCW, (g)	24(48)	–32(48)	43(48)	34(47)	–32(47)	–36(47)
DP, (%)	0.62(0.61)	–0.30(0.61)	0.76(0.61)	0.32(0.63)	–0.30(0.61)	–0.26(0.61)
L*	0.90(0.62)	–0.13(0.62)	–0.05(0.63)	1.00(0.62)	0.16(0.63)	0.94(0.62)
a*	–0.60(0.25)*	0.40(0.25)	0.51(0.25)*	–0.17(0.25)	0.31(0.25)	0.11(0.25)
b*	–0.30(0.46)	0.40(0.46)	0.40(0.46)	0.70(0.46)	0.48(0.46)	0.14(0.46)
CCW, (g)	71(37)	–15(37)	99(37)*	56(37)	32(37)	–35(37)
HW, (g)	–7(3)*	–3(3)	4(3)	7(3)*	4(3)	–6(3)*
LvW, (g)	7(4)	1(4)	6(4)	4(4)	–3(4)	0(4)
KiW, (g)	1(0.5)	0(0.5)	1(0.5)	1(0.5)	0(0.5)	0(0.5)
LHW, (g)	0(1)	0(1)	3(1)*	2(1)	0(1)	0(1)
RCW, (g)	54(32)	–15(32)	85(32)*	45(32)	30(32)	–29(32)
SFaW, (g)	1(1)	1(1)	2(1)*	0(1)	0(1)	0(1)
PFaW, (g)	1(2)	2(2)	5(2)*	2(2)	0(2)	1(2)
HLW, (g)	15(11)	–2(11)	26(11)*	14(11)	8(11)	–4(11)
LW, (g)	13(11)	–3(11)	27(11)*	17(11)	13(11)	–20(11)
FLW, (g)	13(6)*	–5(6)	12(6)*	14(6)*	11(6)	–4(6)
TW, (g)	7(5)	–4(5)	5(5)	5(5)	5(5)	–5(5)
M/B	–0.27(0.22)	0.26(0.22)	0.29(0.22)	–0.15(0.22)	0.08(0.22)	0.43(0.22)

LW63: liveweight at 63 d after fasting. CSkW: commercial skin weight. FGTW: full gastrointestinal tract weight. HCW: hot carcass weight. DP: dressing percentage. L*: lightness of loin surface. a*: redness of loin surface. b*: yellowness of loin surface. CCW: commercial carcass weight. HW: head weight. LvW: liver weight. KiW: kidneys weight. LHW: thoracic viscera weight. RCW: reference carcasses weight. SFaW: scapular fat weight. PFaW: perirenal fat weight. HLW: hind leg weight. LW: loin weight. FLW: fore leg weight. TW: thoracic cage weight. M/B: meat to bone ratio. L: LP line.
*P<0.05 (significant difference at α=0.05).

difference was observed between AL and VV regarding PFaW. However, the magnitude of the contrast was low. The rest of the contrasts regarding dissectible fat were all non significant. For the principal carcass cut traits, only the contrast LH-VV for LW showed a significant effect in favour of the LH, and for the same contrast HLW was close to significance. These differences, around 3% of the mean of the traits, may be important, as loin and hind legs are very important economical cuts of the carcass and, usually, important meat quality traits as proteins, lipids, tenderness, flavour, etc. are measured in them (Pla *et al.*, 1996; Hernández *et al.*, 2006). For M/B ratio, line V was superior to all crossbred genetics groups (being significant for HV-VV and All-VV). This is in disagreement with results obtained in the lines comparisons (Table 2) where line V had the lowest M/B ratio. These contradictory results could be partially explained by heterotic effects present in the crossbreds but not in the pure lines.

The importance of using a particular line either as sire or dam in a cross was assessed by testing the differences between a particular cross and its reciprocal (Table 4). A given cross and its reciprocal were raised on different farms, but connected by line V, which was raised on all the farms. The consequence of this is that the standard errors of the contrasts for the reciprocal effect (Table 4) were higher than for the contrasts between the lines raised on the same farm (Table 2) and for the average of a cross and its reciprocal compared to line V (Table 3). The contrasts for the traits that were measured at the slaughterhouse were not significant. Given the large errors obtained for these contrasts, this means that relevant differences might exist between reciprocal crosses but they could not be detected. This could be important in LW63 and DP because these traits are the most economically relevant. For traits measured at the meat laboratory, significant differences for the contrast AV-VA were observed for a*, CCW, LHW, RCW, SFaW, PFaW, HLW, LW and FLW. Clearly, for this cross, the best performance outcomes were obtained when the A line acted as sire. However, for SFaW and PFaW this contrast could be considered economically unfavourable, but since commercial rabbit carcass is quite lean, this is not a problem at all. For the rest of the contrasts between the reciprocal crosses, the situation is not clear enough to decide whether a cross is preferable over its reciprocal. Mínguez *et al.* (2015) studied the same reciprocal crosses for body weight at 63 d, and did not observe any significant differences. Ragab (2012) studied the same crosses for reproductive traits and observed non-significant differences between reciprocal crosses for the number born alive and weaned. Mínguez *et al.* (2015) showed significant differences between reciprocal crosses in feed conversion ratio in the contrasts AH-HA and LH-HL (the H line was better as dam). The information on reciprocal crosses regarding reproduction, growth, carcass and slaughter traits must be integrated by the breeder in order to decide the best line to act as dam or as sire, according to the needs of the farm. Principally in the AV cross, line A acting as a sire showed better results for slaughter quality traits.

Direct-maternal effects

Differences between direct-maternal effects are shown in Table 5. In the studied traits, significant differences in direct-maternal effects were observed, especially for $G^{I}_{A\text{-}V}$ in carcass quality traits. It has to be noted that these results are in close agreement with the results obtained in the raw comparison between lines (Table 2). However, it can be observed that the standard errors in Table 5 are greater than those for the corresponding contrasts in Table 2, showing that our experiment had higher power to detect differences between lines, than differences between direct-maternal effects. For LW63, there were no significant differences, but there were some indications that the direct-maternal effects of the LP line were the highest. This result partially agrees with results by Mínguez *et al.* (2012), where the LP line was found to be heavier than A and V lines, but not heavier than the H line. Orengo *et al.* (2009) studied crossbreeding parameters for growth traits between A and V lines, and, like us, they did not find any relevant difference for body weight at 60 d between these lines for direct genetic effects. For CSkW, the V line had the lowest effect; correspondingly the contrasts A-V and L-V in Table 2 followed the same pattern. Regarding FGTW and HCW, no significant differences were estimated. Regarding LW63, CSkW, GFTW, HCW and DP, the same pattern was observed as for the differences between the lines. When the contrast in CSkW and FGTW had the same sign, positive in both cases, significant negative differences in DP were estimated. This is because in these cases the differences between LW63 and HCW became high. $G^{I}_{A\text{-}H}$, $G^{I}_{L\text{-}H}$ and $G^{I}_{L\text{-}V}$ reached significant values for DP, in favour of the line H in A-H and L-H, and in favour of the L line in L-V, as happened for the contrasts between the lines (Table 2). For the $G^{I}_{A\text{-}V}$ of DP, a non-significant value was reported (Table 5); however, the contrast between A and V for DP (Table 2) had large magnitude and it was significant. Given the great economic importance of DP, all these results regarding

Table 5: Direct-maternal differences between lines[1] (standard error) for slaughter and carcass quality traits.

Trait	[1] G^I_{A-H}	G^I_{A-L}	G^I_{A-V}	G^I_{H-V}	G^I_{L-H}	G^I_{L-V}
LW63, (g)	13(85)	–10(67)	81(67)	68(67)	23(86)	91(67)
CSkW, (g)	6(12)	3(9)	25(10)*	19(9)*	2(12)	21(9)*
FGTW, (g)	8(17)	–5(13)	4(13)	–4(13)	13(17)	9(13)
HCW, (g)	–27(54)	8(43)	22(43)	49(43)	–35(55)	13(43)
DP, (%)	–1.44(0.68)*	0.63(0.53)	–0.93(0.53)	0.51(0.53)	–2.13(0.68)*	–1.61(0.53)*
L*	0.11(0.67)	–0.34(0.56)	0.53(0.54)	0.42(0.54)	0.50(0.65)	0.91(0.51)
a*	0.01(0.29)	0.05(0.23)	–0.46(0.23)*	–0.46(0.23)*	–0.05(0.29)	–0.52(0.23)*
b*	–0.07(0.54)	–0.15(0.42)	–0.60(0.42)	–0.52(0.42)	0.07(0.54)	–0.45(0.42)
CCW, (g)	133(43)*	71(34)*	142(34)*	9(33)	63(43)	71(34)*
HW, (g)	12(3)*	7(3)*	13(3)*	1(3)	5(3)	61(3)*
LvW, (g)	–2(5)	6(4)*	9(4)*	11(4)*	–8(5)	3(4)
KiW, (g)	1(0.6)	0(0.4)	2(0.4)*	1(0.4)	1(0.6)	1(0.4)
LHW, (g)	1(1)	0(1)	2(1)	1(1)	1(1)	2(1)
RCW, (g)	114(37)*	55(29)	116(29)*	2(29)	59(37)	61(29)*
SFaW, (g)	0(0.7)	1(0.5)*	2(0.5)*	1(0.5)	–1(0.7)	0(0.5)
PFaW, (g)	3(2)	5(2)*	6(2)*	2(2)	–2(2)	0(2)
HLW, (g)	48(13)*	11(10)	37(10)*	–11(10)	37(13)*	26(10)*
LW, (g)	26(14)	20(11)	35(11)*	9(11)	5(14)	15(11)
FLW, (g)	17(7)*	14(6)*	19(5)*	3(5)	2(7)	5(5)
TW, (g)	18(6)*	2(4)	13(4)*	–5(4)	15(6)*	10(4)*
M/B	0.35(0.25)	0.02(0.20)	0.47(0.20)*	0.11(0.20)	0.34(0.25)	0.45(0.20)*

[1] G^I_{i-j} , direct-maternal differences between lines i and j (see text for a complete explanation).
LW63: liveweight at 63 days after fasting. CSkW: commercial skin weight. FGTW: full gastrointestinal tract weight. HCW: hot carcass weight. DP: dressing percentage. L*: lightness of loin surface. a*: redness of loin surface. b*: yellowness of loin surface. CCW: commercial carcass weight. HW: head weight. LvW: liver weight. KiW: kidneys weight. LHW: thoracic viscera weight. RCW: reference carcasses weight. SFaW: scapular fat weight. PFaW: perirenal fat weight. HLW: hind leg weight. LW: loin weight. FLW: fore leg weight. TW: thoracic cage weight. M/B: meat to bone ratio. L: LP line
*$P<0.05$ (significant difference at α=0.05).

either direct-maternal differences (Table 5) or contrast between lines (Table 2) are very relevant, as they could drive slaughterhouses preferences with regard to the lines involved in the crossbred animals they process.

In the colour parameters of the carcass, there were no significant differences for L*, but significant estimates appeared in a* for G^I_{A-V} , G^I_{H-V} and G^I_{L-V} , and in these cases line V had the highest values. Non-significant differences were found for the contrasts in b*, Thus, the concordance for the significant differences between the Table 2 and Table 5 is not complete. Line A had the highest effect on CCW and HW, significant differences were detected between this line and the others. For these traits, there were also significant values for G^I_{L-V} in favour of the L line. The corresponding significant contrast involving line L for CCW and HW did not reach significance in Table 2, but they were in the same direction. Given the magnitude of the contrasts for CCW, up to 11% the mean of the trait, and the economic importance of the trait, these direct-maternal differences become relevant.

There were significant estimates in LvW for G^I_{A-L} , G^I_{A-V} and G^I_{H-V} , in favour of lines A and H, which did not present the corresponding significant results in the contrasts between the lines (Table 2). For KiW, G^I_{A-V} was significant, as was the contrast A-V in the Table 2. However, there were significant differences between the A and H lines (contrast A-H, in favour of the A line), but no significant differences between the direct-maternal effects of these lines. Non-significant differences were observed for LHW. Table 5 shows, for RCW, significant estimates of G^I_{A-H} , G^I_{A-V} and G^I_{L-V} in favour of the A and LP lines. The effects on these traits had a high relationship with the effects on CCW, as was also observed in Table 2. The direct-maternal differences for the fat weights (SFaW and PFaW) were significant between the lines A and LP and between the lines A and V, but they were not economically relevant. HLW is an important cut in the rabbit carcass and G^I_{A-H} , G^I_{A-V} , G^I_{L-H} and G^I_{L-V} were significant in favour of the A and LP lines. For LW, a significant estimate was found for G^I_{A-V} ; in addition, G^I_{A-H} and G^I_{A-L} effects were close to being significant.

For FLW, the A line showed the highest effects with significant estimates of G^I_{A-H}, G^I_{A-L} and G^I_{A-V}. As for HLW, significant estimates were found for TW in G^I_{A-H}, G^I_{A-V}, G^I_{L-H} and G^I_{L-V}, results that agree with the corresponding contrasts between lines shown in Table 2. Significant differences for M/B ratio were found in G^I_{A-V} and G^I_{L-V}.

Piles *et al.* (2004) obtained significant direct genetic effects for live weight at 60 d in a crossbreeding experiment using animals from 2 lines selected for growth traits. These lines were Caldes and R lines, from IRTA and UPV respectively. Similarly, Ouyed *et al.* (2008) obtained significant direct effects for LW63 and DP between Californian (CA) and New-Zealand White (NZ) breeds. Al-Saef *et al.* (2009), using crosses between the V line and the Saudi Gabali found that, in general, the effects of the V line were higher than the effects of the Saudi Gabali. These effects were significant for live weight, HCW, DP, HW and LHW, the fattening period finished at 84 d of age.

Grand-maternal effects

Grand-maternal effect differences between lines are shown in Table 6. Comparing the standard errors of the corresponding contrasts for direct-maternal effects (Table 5) and grand-maternal effects (Table 6) it can be observed that the errors for the latter are smaller than those for the former, showing that our data structure is better suited to estimate grand-maternal effects than direct-maternal effects, and the same was observed for growth traits by Mínguez *et al.* (2015). However the number of contrasts found to be significant for grand-maternal effects are fewer than for direct-maternal effects, clearly indicating that direct-maternal effects are more important than grand-maternal effects. For slaughter traits, non-significant estimates were found, with the only exception of $G^{M'}_{L-V}$ for CSkW, which was significant in favour of V line. Mínguez *et al.* (2015) found a significant estimate for $G^{M'}_{L-V}$ in body weight at

Table 6: [1]Grand-maternal differences between lines (standard error) for slaughter and carcass quality traits.

Trait[2]	[1] $G^{M'}_{A-H}$	$G^{M'}_{A-L}$	$G^{M'}_{A-V}$	$G^{M'}_{H-V}$	$G^{M'}_{L-H}$	$G^{M'}_{L-V}$
LW63, (g)	–12(46)	–34(53)	–59(61)	–47(46)	22(45)	–25(54)
CSkW, (g)	–6(6)	4(7)	–11(8)	–4(6)	–11(6)	–16(7)*
FGTW, (g)	0(9)	–8(10)	–1(12)	2(9)	8(9)	6(10)
HCW, (g)	8(29)	–6(34)	–12(39)	–21(29)	14(29)	–7(34)
DP, (%)	0.59(0.37)	0.59(0.42)	0.78(0.49)	0.19(0.37)	0.01(0.37)	0.20(0.43)
L*	–0.90(0.38)*	–0.56(0.42)	–0.48(0.46)	0.41(0.38)	–0.33(0.38)	0.07(0.43)
a*	0.43(0.16)*	0.42(0.18)*	0.51(0.20)*	0.08(0.16)	0.00(0.16)	0.08(0.18)
b*	0.40(0.30)	0.27(0.34)	0.75(0.38)*	0.35(0.30)	0.13(0.30)	0.48(0.35)
CCW, (g)	–45(23)*	–57(27)*	–69(30)*	–23(23)	12(23)	–11(27)
HW, (g)	–2(2)	–3(2)	–6(2)*	–4(2)*	1(2)	–2(2)
LvW, (g)	–4(3)	0(3)	–4(3)	0(3)	–4(3)	–4(3)
KiW, (g)	–1(0.3)	–1(0.4)	–1(0.4)*	0(0.3)	0(0.3)	0(0.4)
LHW, (g)	–1(1)	1(1)	–1(1)	0(1)	–2(1)	–2(1)*
RCW, (g)	–35(20)	–51(23)*	–53(26)*	–18(20)	16(20)	–2(23)
SFaW, (g)	–0.5(0.4)	0(0.4)	–0.5(0.5)	0(0.4)	–0.5(0.4)	–0.5(0.4)
PFaW, (g)	–1(1)	–2(1)	–2(2)	–1(1)	1(1)	0(1)
HLW, (g)	–10(7)	–17(8)*	–16(9)	–6(7)	7(7)	1(8)
LW, (g)	–15(7)*	–17(8)*	–16(10)	–1(8)	2(6)	1(9)
FLW, (g)	–2(4)	–2(4)	–6(5)	–5(4)	–1(4)	–4(4)
TW, (g)	–10(3)*	–10(4)*	–10(4)*	–1(3)	1(3)	0(4)
M/B	–0.02(0.13)	–0.07(0.15)	–0.35(0.17)*	–0.36(0.13)*	0.06(0.13)	–0.30(0.16)

[1] $G^{M'}_{i-j}$, grand-maternal differences between lines i and j (see text for a more complete explanation).

LW63: liveweight at 63 d after fasting. CSkW: commercial skin weight. FGTW: full gastrointestinal tract weight. HCW: hot carcass weight. DP: dressing percentage. L*: lightness of loin surface. a*: redness of loin surface. b*: yellowness of loin surface. CCW: commercial carcass weight. HW: head weight. LvW: liver weight. KiW: kidneys weight. LHW: thoracic viscera weight. RCW: reference carcasses weight. SFaW: scapular fat weight. PFaW: perirenal fat weight. HLW: hind leg weight. LW: loin weight. FLW: fore leg weight. TW: thoracic cage weight. M/B: meat to bone ratio. L: LP line.

*P<0.05 (significant difference at α=0.05).

63 d, for the same sample but before fasting. In colour traits appeared significant estimates in L* for $G^{M'}_{A-H}$, in a* for $G^{M'}_{A-H}$, $G^{M'}_{A-L}$ and $G^{M'}_{A-V}$ and in b* for $G^{M'}_{A-V}$, all these contrasts favoured A line.

Table 6 shows significant estimates in $G^{M'}_{A-H}$, $G^{M'}_{A-L}$ and $G^{M'}_{A-V}$ for CCW, favouring the lines other than the A. These contrasts were also significant for the direct-maternal effects (Table 5), but in the case of the grand-maternal differences between lines, the values of the contrasts were smaller and of opposite sign. Similarly, regarding CCW the contrasts in Table 6 and those regarding the reciprocal effects (Table 3) do not fit either.

Line A had the smallest effect for HW while V line had the highest. No significant differences were found for LvW, and the significant differences showed for KiW ($G^{M'}_{A-V}$) and for LHW ($G^{M'}_{L-V}$) had a low magnitude. For RCW, as for CCW, A line showed the highest value, and again, these results do not match Table 3, and were opposite to the contrasts regarding direct-maternal effects (Table 5). For dissectible fat weights, significant differences were not observed. Regarding carcass cuts, it was observed that grand-maternal effects associated to A line were unfavourable. The V line showed the most favourable grand-maternal effects for M/B. For this trait, the contrast $G^{M'}_{L-V}$ was not significant but the magnitude of the difference was high. Afifi *et al.* (1994), Piles *et al.* (2004), Ouyed *et al.* (2008) and Al-Saef *et al.* (2009) studied crossbreeding parameter in the same slaughter traits as we are considering, however they did not report any significant effects.

Maternal heterosis.

Estimates of maternal heterosis effects are shown in Table 7. A result which clearly draws attention is that the sign of the majority of the estimates for slaughter and carcass traits were negative. Many results of positive heterosis,

Table 7: [1]Maternal heterosis (standard error) for slaughter and carcass traits.

Trait	[1] H^{M}_{A-H}	H^{M}_{A-L}	H^{M}_{A-V}	H^{M}_{H-V}	H^{M}_{L-H}	H^{M}_{L-V}
LW63, (g)	–46(46)	–47(53)	–26(46)	–43(40)	–27(38)	2(36)
CSkW, (g)	–2(6)	–7(7)	–2(6)	–6(5)	–1(5)	–2(5)
FGTW, (g)	–7(9)	–4(10)	–5(9)	0(8)	6(8)	9(8)
HCW, (g)	–18(30)	–10(34)	–16(30)	–30(25)	–28(25)	0(23)
DP, (%)	0.26(0.37)	0.65(0.43)	–0.04(0.37)	–0.29(0.33)	–0.56(0.32)	–0.14(0.30)
L*	–0.37(0.37)	–0.32(0.43)	–0.31(0.38)	–0.60(0.33)	–0.79(0.33)*	–079(0.31)*
a*	0.41(0.16)*	0.33(0.18)	0.09(0.16)	–0.04(0.13)	–0.07(0.13)	–0.14(0.13)
b*	0.21(0.30)	0.72(0.34)	0.58(0.29)*	–0.48(0.25)	–0.48(0.25)	–0.37(0.25)
CCW, (g)	–36(23)	23(27)	–3(23)	–31(20)	–81(20)*	–32(19)
HW, (g)	–3(2)	–1(2)	–1(2)	2(2)	–5(2)*	–1(2)
LvW, (g)	1(3)	–1(3)	–7(3)*	–3(2)	–7(2)*	–2(2)
KiW, (g)	0(0.3)	0(0.4)	0(0.3)	–1(0.3)*	–1(0.3)*	0(0.3)
LHW, (g)	–2(0.7)*	–2(0.8)*	0(0.7)	–2(0.6)*	–2(0.6)*	–1(0.6)
RCW, (g)	–32(20)	22(23)	1(20)	–25(17)	–66(17)*	–29(17)
SFaW, (g)	0(0.4)	–1(0.4)*	–1(0.4)	0(0.3)	–1(0.3)*	0(0.3)
PFaW, (g)	1(1)	2(1)	–1(1)	–2(1)*	–4(1)*	–2(1)
HLW, (g)	–14(7)*	12(8)	3(7)	–9(6)	–21(6)*	–10(5)
LW, (g)	–7(7)	7(8)	0(7)	–8(6)	–19(6)*	–5(6)
FLW, (g)	–1(4)	8(4)	1(4)	–6(3)	–13(3)*	–8(3)*
TW, (g)	–8(3)	0(3)	1(3)	–1(3)	–4(3)	–2(3)
M/B	–0.39(0.13)*	–0.34(0.15)*	–0.25(0.13)	–0.06(0.11)	–0.11(0.11)	–0.20(0.11)

[1] H^{M}_{i-j}, maternal heterosis between lines i and j.

LW63: liveweight at 63 d after fasting. CSkW: commercial skin weight. FGTW: full gastrointestinal tract weight. HCW: hot carcass weight. DP: dressing percentage. L*: lightness of loin surface. a*: redness of loin surface. b*: yellowness of loin surface. CCW: commercial carcass weight. HW: head weight. LvW: liver weight. KiW: kidneys weight. LHW: thoracic viscera weight. RCW: reference carcasses weight. SFaW: scapular fat weight. PFaW: perirenal fat weight. HLW: hind leg weight. LW: loin weight. FLW: fore leg weight. TW: thoracic cage weight. M/B: meat to bone ratio. L: LP line.

*$P<0.05$ (significant difference at α=0.05).

regarding litter size, have been reported (Brun and Saleil, 1994; Khalil and Afifi, 2000; Baselga, *et al.* 2003; Brun and Baselga, 2005; Youssef *et al*., 2008; Ragab, 2012). This results in higher litter sizes of the crossbred does compared to purebreds, which would penalise body weights (Rouvier *et al.*, 1973; Johnson *et al*., 1988; Lukefahr *et al*., 1990; Ferguson *et al*., 1997). For the contrasts between lines, the relationships between LW63 and slaughter traits and between CCW and carcass traits that were observed was noted. Notice that the estimates involving the lines with higher prolificacy (H and LP lines) (Ragab, 2012) had significant and negative values for their corresponding maternal heterosis, H^{M}_{L-H} , in the majority of the traits measured at the laboratory. However, these significant heterosis estimates only seem relevant for CCW, RCW and cut parts between lines LP and H, for HLW and M/B between lines A and H and for M/B between lines A and LP, as in all these cases differences of up to 5% of the mean were observed. The design of the experiment does not allow the estimation of direct heterosis effects, effects that are expected to be small (Orengo *et al*., 2009). The maternal heterosis effects obtained in this study are basically related to the effects of prolificacy on growth, not to growth itself. However, the results obtained in other experiments are very variable and have not been related to litter size of the dams. Thus, Piles *et al.* (2004) did not obtain significant differences for heterosis in a crossbreeding experiment using animals from C and R strains. With Californian, American Chinchilla and New-Zealand White breeds, Ouyed *et al.* (2011) generally obtained zero or low heterosis for body conformation and carcass traits. Al-Saef *et al.* (2009), using crosses between the V line and the Saudi Gabali, found that the heterosis estimates were mostly positive but only significant for CSkW, HW and LHW. Significant and negative values of heterosis were found by Zabadilová *et al.* (2008) in different crosses between 2 HYPLUS lines for live weight, carcass weight and hind leg weight. In Al-Saef *et al.* (2009) and Zabadilová *et al.* (2008), the young rabbits were slaughtered at 84 d of age.

CONCLUSIONS

Few significant differences were found between lines, but these differences seem to be relevant for DP and CCW, and they imply that A line is that with the best DP and heaviest CCW, while V line showed the worst DP and the lightest CCW. Regarding the comparisons between the crosses and V line, the pure line V was only superior for the differences in M/B ratio. In general, the reciprocal cross effects were not relevant, except for the AV cross, where it was observed that for carcass traits the performance of the cross was better when line A acted as sire. After decomposing the estimates of the genetic group effects into direct-maternal, grand-maternal and maternal heterosis effects, following Dickerson's model, similar patterns of effects to those obtained in the comparison between lines and crosses were obtained for the direct-maternal effects. But grand-maternal effects, in general, were of lower magnitude and of opposite sign than direct-maternal effects. Negative values of maternal heterosis were observed, which could be explained, although it was not tested, by the negative environmental effect that crossbred females provide to their offspring as a consequence of their larger litter sizes compared to the purebred females. However, despite this relationship between growth and litter traits, it has not been common to find negative maternal heterosis in growth traits. A diminution of dressing percentage has been detected in some crossbreds (AL and LV) and care must be taken if these types are used. However, for the other traits any of the crossbred females could be used with similar performance.

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