World Rabbit Science

World Rabbit Sci. 2011, 19: 31 - 41
doi:10.4995/wrs.2011.783

HETEROSIS, DIRECT AND MATERNAL ADDITIVE EFFECTS ON RABBIT GROWTH AND CARCASS TRAITS FROM A CANADIAN EXPERIMENT

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ABSTRACT: A total of 479 male and female rabbits from the Californian (CA), American Chinchilla (CH) and New-Zealand White (NZ) breeds and nine crosses between them were used in this experiment. This study aimed to estimate heterosis and direct and maternal additive effects as well as some non genetic effects on rabbit growth and carcass traits in order to identify the most appropriate crossbreeding plan to use for rabbit meat production under Quebec conditions. Each rabbit was identified and weighed individually at weaning (35 d) and at slaughter (63 d). Rabbits were slaughtered after an 18 h fasting period from feed only. Statistical analyses were performed solving fixed models that allow different variances between genetic types. Significant statistical differences were obtained between genetic types for rabbit growth performance. Rabbits from purebred NZ females mated to CA and NZ males or from CA×NZ and NZ×CH crossbred females mated to NZ males ranked first for live weight at 35 and 63 d body weight and for average daily gain (ADG). ADG of NZ×NZ, NZ×(NZ×CH) and NZ×(CA×NZ) rabbits reached around 50 g/d and their feed conversion ratio was about 3.4. Significant differences between genetic types were observed for all carcass traits except for meat/bone ratio. Rabbits from CH, NZ, CA×NZ and NZ×CH does mated to NZ males, and from NZ does mated to CA males had the highest commercial carcass weight and the lowest commercial carcass yield (CCY), whereas CH×CA rabbits ranked first with a CCY higher by 4 to 8% than rabbits from other genetic types. The highest hind part yields were obtained with CH×CH, CH×NZ and NZ×CH rabbits. Concerning the intermediate part percentages, the highest values corresponded to the highest CCY. The CH breed had unfavourable direct effects but favourable maternal effects on growth traits. The CA breed had negative maternal effects on weight traits from weaning to slaughtering. The CA and CH breeds had positive direct and negative maternal effects on intermediate part yield of the carcass compared to NZ. Direct heterosis effects were found for body weight traits, particularly in the crosses involving the NZ breed, with a magnitude ranging from 5 to 10% of the parental mean.

Key Words: breed, rabbit, growth, carcass, crossbreeding, maternal effects, heterosis.

INTRODUCTION

Nowadays, rabbit meat in Canada is mainly sold on a whole carcass basis. In order to attract the consumer's interest and so increase the production volume, it is necessary to offer the rabbit meat in a more attractive and practical form, such as cut parts. For a long time, the dressing percentage has been the most studied rabbit carcass trait. However, carcass quality can be also defined as the proportion of cut parts such as

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Received *October 2009* - Accepted *October 2010*

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). Commercial rabbit meat is usually produced by a three-way cross involving crossbred females mated to males from a sire line. The crossbred females are obtained by mating males and females from two female lines selected for litter size, while the sire lines are generally selected for growth rate, carcass yield, and meat quality (Baselga, 2004; Pascual and Pla, 2007).

When designing a genetic selection program, two aspects must be considered: the choice of partner lines and their crossbreeding scheme, and the within-line selection. Concerning the choice of partner lines and their optimal utilization, different crossbreeding schemes have to be tested in order to identify or to predict the best combination of lines. Dickerson (1969) has theorized the choice of breeds and breed combinations and proposed a set of parameters allowing the prediction of performance from potential breed combinations.

The aim of the study was to compare different crosses of three rabbit breeds (New-Zealand White, Californian and Chinchilla) and estimate heterosis and direct and maternal additive effects, as well as some non genetic effects (parity, litter size, sex and period) on rabbit growth and carcass traits to identify the best crossbreeding plan to use for rabbit meat production in Quebec (Canada).

MATERIAL AND METHODS

Animals and experimental conditions

The experiment was carried out at the Centre de Recherche en Sciences Animales de Deschambault (CRSAD) rabbitry in Quebec province from January 2007 to May 2008. A total of 479 male and female rabbits from the Californian (CA), American Chinchilla (CH) and New-Zealand White (NZ) breeds and some crosses between them were used for this study. Twelve genetic types were evaluated, including the full factorial crosses between the three breeds, plus three other types made from crossbred females CA×NZ (sire breed given first), CH×CA and NZ×CH and NZ sire. The number of rabbits per type is given in Table 2.

The first generation of specific pathogen-free New Zealand purebred rabbits was acquired in 2002 from the Canadian branch of the Charles River firm. CA and CH purebred rabbits were obtained in the United States from breeders of the American Rabbit Breeder Association (ARBA) and introduced into the CRSAD rabbitry according to the caesarean procedure in order to minimize microbial contamination. Rabbits were housed in closed buildings in flat deck cages. Ventilation, temperature (18°C in maternity and 16°C in fattening in winter) and light (16 h light/24 h in maternity and 8 h light/24 h in fattening) were controlled. Does were first mated at 16 wk of age and then regularly on the 10-12 d after parturition. Kits used for this experiment were weaned at 5 wk of age. Three young rabbits were randomly selected from each litter at weaning. Rabbits were identified, weighed and placed in individual cages for the fattening period. They were fed *ad libitum* a commercial diet covering the requirements for growth (2375 kcal/kg metabolizable energy and 16% crude protein). Feed consumption was recorded weekly on a cage basis. Good quality drinking water was available continuously from nipples. Rabbits were individually weighed 40 min before slaughter, which occurred at 62 and 65 d of age (63±1 d) after an 18 h feed fasting period.

The commercial carcass including liver, kidneys and perirenal fat (without head) was weighed following a 2 h chilling period at 4°C. Carcasses were then frozen at –18°C. Carcasses were later dissected according to the recommendations of Blasco and Ouhayoun, (1996). Intermediate part (back) and hind part of the carcass were weighed. Dressing yield (%) (commercial carcass yield) was calculated as chilled carcass weight×100/live weight. Intermediate part and hind part yields were expressed as percentage of chilled carcass weight. Perirenal fat was collected and weighed to assess carcass adiposity. One of the hind legs was used to measure meat/bone ratio, a major indicator of the total amount of meat in the carcass. Fresh hind leg, cooked hind leg (at standardized conditions under vacuum at 80°C during 2.5 h as described by Blasco *et al*., 1992), and hind leg bone were weighed. The meat/bone ratio was calculated according to Larzul and Rochambeau (2004) as (fresh hind leg weight - hind leg bone weight) / hind leg bone weight.

Statistical analyses

Statistical analyses were performed on the following traits: live weight at 35 d of age (LW35), live weight at 63 d (LW63), average daily weight gain between 35 and 63 d (ADG), average daily feed consumption between 35 and 63 d (AFC), feed conversion ratio (FCR) calculated as the ratio of feed consumption to weight gain between 35 and 63 d, commercial carcass weight (CCW), commercial carcass yield (CCY), intermediate part yield (IP%), hind part yield (HP%), perirenal fat percentage of the carcass (carcass fatness, FW%) and meat/bone ratio of the hind leg (M/B). Traits were analysed using a fixed linear model with genetic type (12 levels), sex, time (4 levels according to slaughter date: Feb-Apr 2007, May-Jul 2007, Nov-Dec 2007, Jan-May 2008), litter size of origin (3 levels: <6, 6+7, 8 and more kits born alive), and parity order (4 levels: 1, 2, 3 to 5, 6 and more) as fixed effects. The MIXED procedure from SAS (2002) allowing for variance differences between genetic types was utilized: indeed, the analyses also included crossbreds from a giant breed, thus improving the estimation of the fixed effects, but these types were not considered in this article as they could not give rise to any estimation of crossbreeding parameters.

There were 11 Dickerson parameters (Dickerson, 1969) to be estimated: a general mean (μ), the direct additive effects of breeds CA and CH, as deviations from that of breed NZ ($g^I_{CA/NZ}$ and $g^I_{CH/NZ}$, respectively), the same for the maternal additive effects ($g^M_{CA/NZ}$ and $g^M_{CH/NZ}$, respectively), direct heterosis effects ($h^I_{CA\times CH}$, $h^I_{CA\times NZ}$ and $h^I_{CH\times NZ}$) and maternal heterosis effects ($h^M_{CA\times CH}$, $h^M_{CA\times NZ}$ and $h^M_{CH\times NZ}$). Starting from the decomposition of the genetic type means into 13 initial Dickerson parameters, then expressing the additive effects as deviations from those of breed NZ leads to the matrix K(12, 11) given in Table 1, linking the genetic type means to the new parameters. According to Komender and Hoeschele (1989), the model for estimation of the parameters can be written as:

$$y = Kp + e$$

where y is the vector of the estimates of the genetic type means resulting from the mixed linear model, p the vector of the Dickerson's parameters after reparameterization, K the matrix linking y to p, with var(e)=V, the (co)variance matrix of the estimates of the genetic types means. The solutions are:

$$p = (K'V^{-1}K)^{-1}K'V^{-1}y \text{ and } var(p) = (K'V^{-1}K)^{-1}$$

The statistical significance of each parameter was tested by a unilateral Student test, at the 5% level.

RESULTS

Fixed effects of parity, litter size, time period and sex

Litter parity significantly influenced LW35, LW63 and some carcass traits (CCW, CCY, FW% and M/B), but not ADG, AFC, FCR, intermediate and hind part yield of the carcass (Table 2 and 3). Generally, LW35, LW63 and commercial carcass weight increased gradually from the 1st to the 5th litter and decreased after the 6th litter. The highest CCY (54.4%) was obtained with rabbits from the 1st litter. Thereafter, CCY decreased by about 2 points of percentage at the 2nd litter and stabilized at 53% after the 3rd litter. In contrast, the lowest perirenal fat percentage was recorded in rabbits from the 1st litter (1.96%), increased at the 2nd (2.24%) litter and stabilized after the 3rd litter. The highest meat/bone ratio values were observed

Table 1: Expression of the 12 genetic type means in the 11 Dickerson's crossbreeding parameters, showing the matrix K.

Genetic type	μ	$g^I_{CA/NZ}$	$g^I_{CH/NZ}$	$g^M_{CA/NZ}$	$g^M_{CH/NZ}$	$h^I_{CA\times CH}$	$h^I_{CA\times NZ}$	$h^I_{CH\times NZ}$	$h^M_{CA\times CH}$	$h^M_{CA\times NZ}$	$h^M_{CH\times NZ}$
CA×CA	1	1	0	1	0	0	0	0	0	0	0
CA×CH	1	0.5	0.5	0	1	1	0	0	0	0	0
CA×NZ	1	0 .5	0	0	0	0	1	0	0	0	0
CH×CA	1	0.5	0.5	1	0	1	0	0	0	0	0
CH×CH	1	0	1	0	1	0	0	0	0	0	0
CH×NZ	1	0	0.5	0	0	0	0	1	0	0	0
NZ×CA	1	0.5	0	1	0	0	1	0	0	0	0
NZ×CH	1	0	0.5	0	1	0	0	1	0	0	0
NZ×NZ	1	0	0	0	0	0	0	0	0	0	0
NZ×(CA×NZ)	1	0.25	0	0.5	0	0	0.5	0	0	1	0
NZ×(CH×CA)	1	0.25	0.25	0.5	0.5	0	0.5	0.5	1	0	0
NZ×(NZ×CH)	1	0	0.25	0	0.5	0	0	0.5	0	0	1

In the genetic type, the sire breed is given first: CA, CH and NZ: Californian, American Chinchilla and New-Zealand White breed, respectively.

μ: general mean.

$g^I_{X/Y}$ (resp. $g^M_{X/Y}$): additive direct (resp. maternal) effect of the X breed, as deviation from the Y breed.

$h^I_{X/Y}$ (resp. $g^M_{X/Y}$):: individual (resp. maternal) heterosis in the cross between the X and Y breeds.

Table 2: Statistical significance of the fixed effects (*P*-values), estimates of genetic type means and of Dickerson's crossbreeding parameters for growth and feed consumption traits.

	No.	Live weight at 35 d (g)	Live weight at 63 d (g)	Daily weight gain (g/d)	Daily feed consumption (g/d)	Feed consumption ratio
Genetic type		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Parity		<0.0001	<0.0001	0.3579	0.0561	0.6320
Litter size		<0.0001	<0.0001	<0.001	<0.0001	<0.05
Sex		0.1627	0.5656	0.5779	0.2549	0.1452
Period		<0.01	<0.0001	<0.0001	<0.01	0.1841
Genetic type estimates[1]						
CA×CA	35	930 ± 24^{ab}	2199 ± 38^{bc}	45.7 ± 0.9^{b}	223 ± 10^{fg}	4.96 ± 0.28^{gh}
CA×CH	37	962 ± 33^{b}	2165 ± 47^{b}	43.1 ± 0.9^{b}	210 ± 11^{efg}	4.84 ± 0.25^{h}
CA×NZ	65	1097 ± 17^{e}	2470 ± 28^{e}	49.3 ± 0.7^{cd}	203 ± 6^{bcde}	4.10 ± 0.15^{bdef}
CH×CA	47	962 ± 19^{b}	2037 ± 35^{a}	38.9 ± 0.9^{a}	231 ± 10^{g}	5.84 ± 0.24^{i}
CH×CH	20	880 ± 24^{a}	1934 ± 36^{a}	38.3 ± 0.9^{a}	174 ± 11^{abcd}	4.48 ± 0.26^{fgh}
CH×NZ	48	1046 ± 22^{cde}	2318 ± 39^{cd}	45.2 ± 0.9^{b}	184 ± 7^{abc}	4.09 ± 0.18^{bcde}
NZ×CA	15	1009 ± 31^{bcd}	2360 ± 58^{de}	46.8 ± 1.4^{bc}	209 ± 15^{bef}	4.40 ± 0.30^{dfgh}
NZ×CH	18	1006 ± 27^{bc}	2376 ± 29^{de}	49.0 ± 0.7^{cd}	186 ± 7^{abcd}	3.75 ± 0.15^{abcde}
NZ×NZ	41	1055 ± 25^{cde}	2465 ± 45^{e}	50.7 ± 1.0^{d}	178 ± 6^{a}	3.43 ± 0.13^{a}
NZ×(CA×NZ)	62	1056 ± 28^{cde}	2464 ± 49^{e}	50.8 ± 1.0^{d}	185 ± 7^{ab}	3.54 ± 0.14^{a}
NZ×(CH×CA)	46	938 ± 21^{b}	2271 ± 34^{bcd}	47.6 ± 0.9^{bc}	205 ± 9^{bcef}	4.36 ± 0.21^{def}
NZ×(NZ×CH)	45	1072 ± 22^{de}	2486 ± 46^{e}	50.5 ± 1.1^{d}	178 ± 6^{a}	3.45 ± 0.13^{a}
Dickerson's crossbreeding parameters[2]						
$g^{I}_{CA/NZ}$		-45 ± 54	-98 ± 88	1.8 ± 2.0	$32\pm20^{*}$	$0.91\pm0.50^{*}$
$g^{I}_{CH/NZ}$		$-99\pm41^{*}$	$-502\pm67^{*}$	$-13.3\pm1.6^{*}$	3 ± 14	$1.42\pm0.32^{*}$
$g^{M}_{CA/NZ}$		$-86\pm38^{*}$	$-189\pm61^{*}$	$-3.9\pm1.4^{*}$	10 ± 15	$0.60\pm0.34^{*}$
$g^{M}_{CH/NZ}$		$-69\pm27^{*}$	-10 ± 40	$1.7\pm1.0^{*}$	-4 ± 9	$-0.36\pm0.20^{*}$
$h^{I}_{CA\times CH}$		$61\pm25^{*}$	42 ± 39	-1.0 ± 0.9	$22\pm10^{*}$	$0.63\pm0.26^{*}$
$h^{I}_{CA\times NZ}$		$85\pm23^{*}$	$233\pm39^{*}$	$4.4\pm0.9^{*}$	$20\pm8^{*}$	-0.05 ± 0.19
$h^{I}_{CH\times NZ}$		$52\pm24^{*}$	$148\pm37^{*}$	$2.5\pm0.9^{*}$	7 ± 8	-0.04 ± 0.18
$h^{M}_{CA\times CH}$		$-72\pm30^{*}$	$-135\pm45^{*}$	-1.6 ± 1.1	1.4 ± 11	0.27 ± 0.26
$h^{M}_{CA\times NZ}$		13 ± 33	1.5 ± 58	0.3 ± 1.3	$-16\pm9^{*}$	$-0.39\pm0.20^{*}$
$h^{M}_{CH\times NZ}$		$50\pm28^{*}$	77 ± 53	1.1 ± 1.3	-3 ± 8	-0.13 ± 0.16

[1] In the genetic type, the sire breed is given first: CA, CH and NZ: Californian, American Chinchilla and New-Zealand White breed, respectively. Means in the same column with different superscripts are significantly different at 5%.

μ: general mean.

$g^{I}_{X/Y}$ (resp. $g^{M}_{X/Y}$): additive direct (resp. maternal) effect of the X breed, as deviation from the Y breed.

$h^{I}_{X/Y}$ (resp. $g^{M}_{X/Y}$): individual (resp. maternal) heterosis in the cross between the X and Y breeds.

An * as superscript indicates values significantly different from zero at 5%.

in rabbits from the 2nd and 6th litter and more, whereas the lowest were recorded in rabbits from the 1st and the 3rd to 5th litter.

Table 3: Statistical significance of the fixed effects (*P*-values), estimates of genetic type means and of Dickerson's parameters for body composition variables.

	No.	Carcass weight (g)	Carcass yield (%)	Hind part yield (%)	Intermediate part yield (%)	Fat percentage of the carcass (%)	Muscle/bone ratio of the hind leg
Genetic type		<0.0001	<0.05	<0.01	<0.0001	<0.0001	NS
Parity		<0.05	<0.05	0.3559	0.1105	<0.05	<0.05
Litter size		<0.0001	0.1042	0.3513	<0.05	0.1476	0.4877
Sex		0.3527	0.4553	0.1982	0.2707	0.7443	0.1352
Period		<0.0001	<0.01	<0.05	<0.05	0.1241	<0.0001
Genetic type estimates[1]							
CA×CA	35	1096±24^{cd}	54.7±0.9^{b}	34.9±0.3^{abc}	30.3±0.5^{bc}	1.66±0.09^{a}	5.53±0.22
CA×CH	37	1099±30^{bcd}	54.7±0.5^{bc}	35.6±0.4^{acde}	30.2±0.5^{bc}	1.97±0.09^{abc}	5.63±0.21
CA×NZ	65	1185±17^{e}	53.1±0.6^{a}	35.1±0.3^{abc}	30.1±0.3^{c}	2.07±0.08^{be}	5.38±0.20
CH×CA	47	1042±19^{ab}	56.0±0.6^{c}	35.5±0.2^{acde}	30.3±0.3^{c}	1.88±0.08^{ab}	5.59±0.20
CH×CH	20	978±23^{a}	54.5±0.6^{abc}	36.2±0.4^{de}	29.2±0.8^{ac}	1.76±0.13^{ab}	5.79±0.43
CH×NZ	48	1109±23^{cd}	53.5±0.7^{ab}	36.4±0.3^{e}	29.5±0.4^{ac}	2.28±0.12^{def}	5.65±0.18
NZ×CA	15	1150±31de	53.1±1.0^{ab}	34.7±0.5^{a}	28.6±0.6^{a}	1.98±0.14^{abd}	5.04±0.34
NZ×CH	18	1190±23^{e}	54.4±0.8^{ab}	36.1±0.4^{de}	28.4±0.5^{a}	2.38±0.15^{def}	5.27±0.29
NZ×NZ	41	1172±24^{e}	52.9±0.7^{a}	35.9±0.3^{de}	28.5±0.4^{a}	2.18±0.09^{cdef}	4.97±0.24
NZ×(CA×NZ)	62	1181±26^{e}	53.3±0.6^{a}	34.8±0.3^{ab}	29.2±0.4^{ab}	2.19±0.11^{cdef}	5.30±0.22
NZ×(CH×CA)	46	1077±20^{bc}	53.0±0.6^{a}	35.4±0.3^{abcd}	29.1±0.4^{a}	2.11±0.09^{cdef}	5.53±0.22
NZ×(Z×CH)	45	1185±25^{e}	53.3±0.6^{a}	35.3±0.3^{abcd}	28.8±0.4^{a}	2.27±0.11^{df}	5.90±0.22
Dickerson's crossbreeding parameters[2]							
$g^{I}_{CA/NZ}$		−29±53	0.4±1.5	−0.9±0.7	3.1±0.9*	−0.48±0.22*	0.91±0.51*
$g^{I}_{CH/NZ}$		−208±40*	1.6±1.2	0.2±0.6	2.4±0.8*	−0.47±0.18*	1.09±0.48*
$g^{M}_{CA/NZ}$		−62±36*	1.4±1.0	−0.1±0.5	−1.5±0.7*	−0.04±0.16	−0.33±0.36
$g^{M}_{CH/NZ}$		27±26	0.2±0.8	−0.0±0.4	−1.4±0.5*	0.05±0.13	−0.33±0.28
$h^{I}_{CA\times CH}$		41±24*	0.7±0.6	0.0±0.3	0.5±0.5	0.21±0.10*	−0.03±0.28
$h^{I}_{CA\times NZ}$		103±23*	−0.7±0.7	−0.9±0.3*	0.3±0.5	0.11±0.10	−0.11±0.26
$h^{I}_{CH\times NZ}$		68±23*	0.2±0.7	0.3±0.4	−0.1±0.5	0.35±0.12*	0.12±0.27
$h^{M}_{CA\times CH}$		−104±27*	−0.9±0.9	0.0±0.4	0.5±0.5	−0.07±0.14	0.38±0.31
$h^{M}_{CA\times NZ}$		−4±31	−0.0±0.8	−0.5±0.4	0.5±0.5	0.09±0.13	0.32±0.29
$h^{M}_{CH\times NZ}$		17±29	−0.2±0.8	−0.7±0.4*	0.5±0.5	0.00±0.13	0.76±0.28*

[1] In the nomenclature on the genetic type, the sire breed is given first: CA, CH and NZ: Californian, American Chinchilla and New-Zealand White breed, respectively. Means in the same column with different superscripts are significantly different at 5%.

μ: general mean.

$g^{I}_{X/Y}$ (resp. $g^{M}_{X/Y}$): additive direct (resp. maternal) effect of the X breed, as deviation from the Y breed.

$h^{I}_{X/Y}$ (resp. $g^{M}_{X/Y}$): individual (resp. maternal) heterosis in the cross between the X and Y breeds.

An * as superscript indicates values significantly different from zero at 5%.

There was a significant effect ($P<0.05$) of litter size on LW35, LW63, ADG, AFC, FCR, CCW and intermediate part yield IP%. In fact, LW35, LW63, ADG, AFC and CCW were lower by about 15, 9.5, 4, 11 and 6% respectively when rabbits came from litters with 8 and more kits than those coming from litters with less than 6 kits. On the other hand, FCR and IP% were improved with increasing litter size. Rabbits coming from litters with more than 8 kits showed better performance for these two parameters than those from litters with less than 6 kits (3.75 *vs* 4.08 g/g for FCR and 29 *vs* 28% for IP%).

The raising period also had a significant effect on growth performance (LW35, LW63, ADG and AFC) and carcass traits (CCW, CCY, IP%, HP% and M/B). Rabbits slaughtered in the January-May 2008 period had better LW63 (2513.2 g), ADG (52.6 g/d) and AFC (212.8 g/d) when compared to other periods, except for LW35 where the highest value was obtained in November-December 2007. Rabbits slaughtered during the November-December 2007 period were those with the highest CCW, IP% and M/B. However, the best CCY (54.8%) and HP% (36.1%) were recorded when rabbits were slaughtered from May to July 2007.

Finally, sex had no significant effects on growth performance and carcass traits.

Genetic type means

Rabbit genetic types influenced ($P<0.0001$) growth performance (Table 2). Rabbits from NZ purebred females mated to CA, NZ and CH males or from CA×NZ and NZ×CH crossbred females mated to NZ males ranked first for LW35. In this leading group, LW35 varied from 1046 22 g for CH×NZ rabbits to 1097±17 g for CA×NZ rabbits. Conversely, CH×CH purebred rabbits (880±24 g) and CA×CA (930±24 g) had the lowest LW35.

Rabbits from NZ females mated to NZ or CA males and from NZ×CH or CA×NZ females mated to NZ males had the highest LW63. In this leading group, LW63 varied from 2464±49 g for NZ×(CA×NZ) rabbits to 2486±46 g for NZ×(NZ×CH) rabbits. ADG of these rabbits was around 50 g/d. On the other hand, rabbits with the worst LW63 and ADG were those coming from CA and CH females mated to CH males.

Genetic types also affected feed consumption and feed efficiency. Rabbits from the NZ×NZ, NZ×(CA×NZ) and NZ×(NZ×CH) genetic types showed the best FCR with values ranging from 3.43 to 3.54. They consumed between 178 and 185 g/d grew about 50 g/d during the fattening period. CH×CH rabbits had the lowest AFC (174 g/d), but their low ADG did not allow a good FCR. Rabbits from CH×CA and CA×CA genetic types were those with the highest AFC and FCR (Table 2). Overall, FCR was positively correlated with ADG.

Significant differences between genetic types were observed for all carcass traits except for meat/bone ratio (Table 3). CCW ranged from 978±23 (CH×CH) to 1190±23 g (NZ×CH). Rabbits coming from CH, NZ, CA×NZ and NZ×CH does mated to NZ males, and from NZ does mated to CA males had the highest CCW, which is higher by 20% than the CH×CH rabbits, the less interesting breed for CCW. Conversely, rabbits with the highest CCW seemed to have the lowest CCY, with values ranging between 52 to 54%, whereas CH×CA rabbits ranked first with a CCY higher by 4 to 8% than rabbits from others genetic types.

The highest values for HP% were obtained with CH×CH, CH×NZ and NZ×CH rabbits. The NZ×CA rabbits had the lowest HP% (34.7%). The highest values for IP% were observed with (CA×CA, CA×CH, CA×NZ and CH×CA) rabbits and corresponded, except for CA×NZ, to the highest CCY.

FW%, a good predictor of carcass fatness, varied from 1.66 to 2.38%. Rabbits coming from crosses between NZ and CH lines were characterized by the highest carcass fat deposition (2.28% for CH×NZ and 2.38% for NZ×CH). In general, FW% was positively correlated with ADG and FCR.

Dickerson's genetic parameters

Direct additive effects. With respect to genes from the NZ breed, genes from the CH breed decreased LW35, ADG and LW63. They did not influence AFC but significantly hampered the FCR. Genes from the

CA breed did not alter growth rate but significantly increased AFC and the FCR. Additive genetic effects did not influence carcass yield but did influence some carcass composition traits. The CA and CH genes increased the IP% and the M/B, whereas they decreased FW%.

Maternal additive effects. CA breed had negative maternal effects on LW35, ADG and LW63. It also had negative effects on FCR. Conversely, CH breed had favourable maternal effects on ADG and FCR. As far as carcass conformation and composition are concerned, negative maternal effects of CA and CH breeds were evidenced for the IP%. CCY was not influenced by additive maternal effects.

Individual heterosis. Overall, LW35, LW63, ADG and CCW benefited from individual heterosis, except ADG and LW63 in the CA×CH cross. Moreover, the CA×CH crossbred rabbits consumed more feed than the parental average and had a lower FCR. Carcass composition traits were generally not affected by individual heterosis except for the lower HP% in the CA×NZ crossbreds and the higher CA×CH and CH×NZ crossbreds' FW%.

Maternal heterosis. The CA×CH crossbred does exerted a negative maternal heterosis on rabbit weights including carcass weight. Conversely, the CH×NZ crossbred does had a positive maternal heterosis effect on LW35. The CA×NZ does lead to a maternal heterosis, which was reflected in improved FCR. As for individual heterosis, carcass composition traits were rarely affected by maternal heterosis. Nevertheless, the CH×NZ cross leads to maternal heterosis which decreased HP% and increased the M/B, an indicator of the carcass muscle content.

DISCUSSION

Fixed effects of parity, litter size, time period and sex

Result from this study showed significant statistical effects of parity, litter size and time period on growth traits and carcass traits. However, there was no gender influence. Generally, LW35, LW63 and CCW increased gradually until the 5th litter and decreased thereafter. While CCY decreased from the 1st to 2nd litter and stabilized after the 3rd litter, the PW% increased from the 1st to the 2nd litter and stayed stable after the 3rd litter. These results support those reported by Ouyed *et al*. (2007) with regard to LW63 which decreased after the 4th litter. Also, Prayaga and Eady (2003) reported that the individual body weights at 5 and 10 wk of age were significantly lower in the 1st parity born rabbits than in other higher parity born rabbits. However, they reported significantly higher carcass weights in the 2nd and 3rd parity litters than in 1st and 4th ones. Ozimba and Lukefahr (1991) did not report any significant effect of litter parity on rabbit growth traits.

Except for FCR and CCW, growth parameters gradually deteriorated with increased litter size. In contrast, FCR and IP% were improved when litter size increased. These results are in agreement with those of Orengo *et al*. (2004), where better growth traits and commercial carcass weight were obtained when litter size at birth was lower.

Growth performance and carcass traits tended to improve with time period. As the rearing conditions in the CRSAD experimental rabbitry were controlled and maintained constant for all season except for summer (not covered at all in this study), this trend may be explained by the breeder's selection programme used at CRSAD.

Genetic types and Dickerson's parameter estimates

Rabbit populations used in crossbreeding experiments are just specific strains extracted from larger breed populations and their genetic effects can vary depending upon their selection history, including founder effects. As an example, in a crossbreeding experiment involving two INRA strains based on the NZ breed (one selected for litter size and its unselected control) and one strain from the CA breed selected for litter size, additive direct and maternal effects for ADG, carcass yield or edible part of the hind leg are more similar between strains submitted to the same selection criterion than between strains coming from the same breed (Brun and Ouhayoun, 1989). Moreover, genotype by environment interactions can alter the effect of any strain according to the type of environment. Consequently, discrepancies concerning the ranking of genetic types or the estimates of crossbreeding parameters in the present experiment with previous studies involving the same breeds should come as no surprise.

It seems from this study that the use of NZ purebred females mated to CA, NZ and CH purebred males, or the use of CA×NZ and NZ×CH crossbred females with NZ males, produce heavier rabbits at weaning compared to other crossbreeding plans. On the other hand, the use of CA and CH rabbit does in pure breeding or in crossbreeding leads to offspring with the lowest LW35. These results may be partly explained by good maternal abilities and high milk production of NZ, CA×NZ and NZ×CH females (Ouyed, 2009), as estimated from litter weight gain from 0 to 21 d according to Fortun-Lamothe and Sabaster (2003). These maternal effects are quantified by favourable maternal additive effects of the NZ breed with respect to CA breed, and maternal heterosis in the NZ×CH cross.

LW63 and ADG of rabbits were improved on average by 19% and 21% respectively when using NZ×CH and CA×NZ crossbred females mated to NZ males, or purebred NZ females mated to NZ or CA males, compared to the use of the CA and CH, in pure breeding or in reciprocal crossbreeding. Moreover, AFC decreased and the FCR improved with the use of NZ, NZ×CH and CA×NZ in crossbreeding with NZ. In contrast, AFC was higher and FCR deteriorated when CA and CH males and females were used, either in pure or crossbreeding selection plans. Overall, growth performance rates, as expressed by ADG and LW63, were influenced by genetic types. Offspring from NZ females had better performances than those from CA females (Ouyed and Brun, 2008).

Our results showed that rabbits with the lowest LW63 also had the highest CCY. This could be explained by the lower proportion of head and skin found in these rabbits, but it is not possible to confirm this hypothesis as these parts were not measured in this study. Lebas and Ouhayoun (1987) reported such a correlation between slaughter weight and carcass yield, where rabbits reared in summer displayed both a lighter live weight at slaughter and a higher CCY because of their lower head and skin proportion.

Breed type differences for carcass traits have often been reported (Lukefahr *et al*., 1983; Ozimba and Lukefahr, 1991; Nofal *et al*., 2004). Prayaga and Eady (2003) reported that CA purebreds and crossbreds had the lowest performances, both for growth and slaughter traits, except for dressing out percentage. Lukefahr *et al*. (1983) also reported higher dressing percentage in rabbits coming from CA lines when compared to the NZ lines, although our findings did not coincide with these results.

Concerning cut parts, it appears that using the CA breed in a crossbreeding plan allows a considerable improvement in the IP%, whereas the use of the CH breed increases HP%. These results are confirmed by the estimated direct additive effects of CA and CH breeds on both traits, respectively.

In our study, the CH strain had unfavourable direct effects but positive maternal effects on ADG. The CA strain presented the opposite trend. This opposition between direct and maternal effects on growth is in accordance with other results from crossbreeding experiments (Brun and Ouhayoun, 1994) even if it cannot be stated as a general rule. The negative maternal effects of CA breed on weight traits from weaning to slaughter are in agreement with results from Brun and Ouhayoun (1989) and are likely linked to the higher ovulation rate and litter size of this breed. Interestingly, FCR is dependant on both direct and maternal gene effects, with a balance between opposing unfavourable direct effects and favourable maternal effects of the CH breed. The positive correlation between ADG and FCR observed for the direct effects as well as for the maternal effects is in agreement with the usual results (Ollivier and Henry, 1978, in pigs; Ouhayoun, 1978, in rabbits).

Direct heterosis effects were found on body weight traits, particularly in the crosses involving the NZ breed, with a magnitude from 4% to 7% of the parental average, in accordance with published results (Brun and Ouhayoun, 1989, Medellin and Lukefahr, 2001; Piles *et al*., 2004). The presence of heterosis in ADG between 35 and 63 d does not coincide with results generally observed for this trait (Brun and Ouhayoun, 1984 and 1989, Piles *et al*., 2004, Gomez *et al*., 1999), albeit with some exceptions. While body conformation and carcass composition related traits generally exhibit zero or low heterosis, two instances were found in our experiment for direct or maternal heterosis for HP%, two others for WF% and one for M/B (Table 3).

Practical implications

This study showed that NZ pure breed, NZ×CH and CA×NZ crossbred females had higher LW 35, LW63, ADG and CCW. Also, when considering a synthetic criterion for carcass quality (the total weight of the back + the hind legs), which takes into account the carcass weight and IP%+HP%, the CA×NZ single crossbreds rank first (772 g), followed by rabbits from NZ×CH and CA×NZ crossbred females mated with NZ males (758 and 756 g, respectively) and by NZ rabbits from pure breeding (754 g). From a practical point of view, the use of the NZ breed in pure breeding is feasible. On the other hand, a crossbreeding scheme involving crossbred does would be justified by the performance of the lines that produce the crossbred does and their heterosis effect on litter size (Ouyed *et al*., 2007 and Ouyed, 2009).

CONCLUSIONS

Our study confirms genetic type effects for rabbit growth and carcass quality traits, even when comparing breeds with similar body size. Crossbreeding is a useful tool for both genetic improvement and for the genetic analysis of traits, allowing us to isolate direct and maternal effects and estimate heterosis. Our study confirms that parental strains of similar body size may influence growth and carcass quality through different direct and maternal effects: additive direct effects influence feed efficiency and carcass weight - with negative values for the CH strain - and also impact the intermediate and hind part percentage of the carcass - with contrasting effects for the CA strain. Maternal effects also influence carcass weight and feed efficiency, acting in some cases in opposition to direct effects. Finally, direct and maternal heterosis are demonstrated for body and carcass weights and even for some carcass traits.

Acknowledgements: This work was carried out in association with the Regroupement pour l'Amélioration Génétique Cunicole du Québec (RAGCQ), the CRSAD, the Syndicat des Producteurs de Lapins du Québec (SPLQ), Kunipac slaughterhouse and the École Hôtelière de la Capitale (EHC). It was financially supported in part by the Conseil pour le Développement de l'Agriculture au Québec (CDAQ) and the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ). A special thank goes to the technical staff of CRSAD for the quality of their work in the rabbitry.

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