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The effect of selection for growth rate on carcass composition and meat characteristics of rabbits

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Abstract

The effect of selection for growth rate on carcass composition and meat quality was assessed by comparing two groups of rabbits belonging to different generations of a selection experiment. A Bayesian approach was used. Embryos belonging to generations 3 and 4 of selection were frozen and thawed to be contemporary of animals from generation 10. A control group (C), formed from offspring of these embryos, was contemporary to offspring of generations 10 and 11 of selection, chosen at random, which constituted the selected group (S). One hundred and thirty-one contemporary rabbits were slaughtered at approximately the Spanish commercial live weight of 2 kg. Carcasses were dissected and measured according to the norms of the World Rabbit Scientific Association. An animal model including effects of genetic group (C, S) and sex, and slaughter weight as a covariate was used. S animals had a higher development of liver, kidneys and of a set of organs consisting of the thymus, trachea, oesophagus, lung and heart, relative to C. For dissectible fat, S animals had less than C: −0.31 g for scapular fat, −1.62 g for perirenal fat and −2.03 g for inguinal fat. S had a lower content (−0.39%) of dissectible fat percentage in the "Reference" carcass, indicating a lower degree of maturity at slaughter. The meat to bone ratio was not affected by selection, but the meat and bone contents of the hind leg were 3.25 and 0.71 g higher, respectively, in the C group. Selected animals had a lower water holding capacity in the raw meat (−2.10%), a higher water holding capacity in the cooked meat (2.17%), a higher cooking loss (3.31%) and a lower fat percentage in the meat of a hind leg (−0.37%). Females had more fat than males: 0.26 g for scapular fat, 1.02 g for perirenal fat, 1.10 g for inguinal fat, and 0.24% for total dissectible fat percentage of the "Reference" carcass.

Keywords: Rabbit; Carcass quality; Meat quality; Selection

1. Introduction

Meat rabbit production is based on three-way crosses between specialised lines. Females are from crossbred lines selected for litter size, whereas terminal sires come from lines selected for high growth rate. Selection for growth rate leads to lower age at slaughter weight, an increased live weight during the growth period and a larger adult weight (Blasco, Piles, Rodriguez & Pla, 1996). This could produce undesirable changes in carcass composition and meat quality due to the lower degree of maturity at slaughter. Changes in carcass composition must be monitored carefully in view of the recently developed market for retail cuts. Moreover, carcass yield can also be affected by selection, with adverse consequences for farmers when animals are graded, as is done in Europe.

There is little information about the consequences of selection for faster growth on meat quality. Some experiments have found a loss of meat quality: Kempster, Dilworth, Evans and Fischer (1986) in pigs, Le Bihan-Duval, Millet, Wacrenier, Berri and Beaumont (1999) in poultry and Aass (1996) in cattle. In rabbits, some reports have been based on comparisons between breeds or strains selected for different criteria (e.g., reproductive and growth traits): Rouvier (1970); Lukefahr, Hohenboken, Cheeke, Patton and Kennitch (1982); Lukefahr, Hohenboken, Cheeke and Patton (1983); Perrier and Ouhayoun (1990); Ozimba and Lukefahr (1991); Pla, Hernández and Blasco (1996); Pla, Guerro, Guardia, Oliver and Blasco (1998). However, there is no information in the literature on the effects of selection for growth rate in rabbits.

The objective of this study was to assess the effects of selection for increased growth rate on carcass composition

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and meat quality of rabbits. A Bayesian framework was used for the statistical analysis. An advantage of this approach is that it gives a better description of the uncertainty about the estimates (Gianola & Fernando, 1986) This is particularly relevant in situations in which data gathering is expensive, so the size of the experiment is necessarily low. This was the situation in the present study.

2. Materials and methods

2.1. Animals

Animals originated from a synthetic line that has been selected since 1980 for high growth rate between the 4th and 9th weeks of life, using mass selection (Estany, Camacho, Baselga & Blasco, 1992). This line was formed by crossing a Californian line with a synthetic line created by mating commercial crossbred rabbits. Matings involved approximately 25 males and 90 females per generation. Table 1 shows the weighted selection differentials for the first 10 generations of selection.

Embryos belonging to generations 3 and 4 of selection were frozen and thawed to be contemporary of animals born in generation 10. The procedure was described by Vicente and García-Ximenez (1993a,b). A control group (C) was derived from mating four males and two females from generation 3, and one male and three females from generation 4. Animals belonging to different generations were unrelated, genetically. The control group was formed from offspring of these embryos, to avoid effect of cryoconservation, and was maintained closed and contemporary to rabbits from generations 11 and 12 of the selection line. One hundred and twenty seven rabbits of group C, 76 rabbits of generation 11 and 65 of generation 12, chosen at random, were used to assess the effects of selection for growth rate. Sixty-six rabbits of the control group and 65 rabbits of generation 12 were used to assess the correlated effects of selection on meat and carcass quality.

Table 1
Weighted selection differentials in grams per generation (S)

Generation	N[a]	NSM[b]	NSF[c]	S-males	S-females
1	1583	70	23	8.90	2.94
2	1111	88	25	8.12	6.64
3	1192	95	27	1.47	1.00
4	1508	81	23	6.35	4.51
5	1191	66	18	3.17	0.65
6	861	68	23	6.61	3.54
7	999	80	24	4.73	3.26
8	1245	74	23	4.51	1.79
9	802	44	22	7.39	1.32
10	400	62	16	2.67	1.28

[a] N, number of rabbits of the corresponding generation.
[b] NSM, number of selected males in the corresponding generation.
[c] NSF, number of selected females in the corresponding generation.

Animals were reared at the experimental farm of the Universidad Politécnica de Valencia. After weaning at 4 weeks of age, rabbits were placed in collective cages with eight individuals each, and fed ad libitum with a commercial pelleted food (16.0% crude protein, 15.5% fibre, 3.4% fat) until 9 weeks of age, at which commercial slaughter weight in Spain (about 2 kg) was expected to be reached. Rabbits were slaughtered at the farm, so there was no stress due to transport. No fastening was practised. Hot carcasses were put in a ventilated area for 1 h, and were then stored at 3–5°C for 24 h.

2.2. Growth variables

The traits recorded were: weaning weight (WW), slaughter weight (SW) and daily gain during the 63-day post-weaning growth period (DG = SW − WW/63).

2.3. Carcass quality variables

Carcasses were butchered, and traits recorded following the norms of the World Rabbit Scientific Association (Blasco & Ouhayoun, 1996). After slaughter, blood, skin, distal parts of the tail, fore and hind legs, gastrointestinal and urogenital tracts were removed to obtain the Spanish commercial carcass. This carcass includes head, liver, lungs, thymus, oesophagus, heart and kidneys. These organs were also removed to obtain the ''Reference'' carcass (Blasco & Ouhayoun) enabling comparisons between carcasses from different countries.

Traits recorded were: full gastrointestinal tract weight (FGTW), chilled carcass weight (CCW), reference carcass weight (RCW), liver weight (LvW), weight of kidneys (KiW), weight of a set of organs consisting of the thymus, trachea, oesophagus, lung and heart weight (LHW), head weight (HW), perirenal fat weight (PFaW), scapular fat weight (SFaW), inguinal fat weight (IFaW), dissectible fat weight of the ''Reference'' carcass (DFaW = SFaW + PFaW + IFaW), meat weight of a hind leg (MHLW) and bone weight of a hind leg (BHLW).

Joints obtained according to the Technological Division (Blasco & Ouhayoun, 1996) were weighed, and consisted of: fore legs, including insertion and thoracic muscles (FLW), thoracic cage (TCW), intermediate part (IPW) and hind part (HPW).

The following ratios were calculated: dressing out percentage (DoP = 100×CCW/SW), liver percentage (LvP = 100×LvW/SW), kidneys percentage (KiP = 100×KiP/SW), set of organs consisting of thymus, trachea, oesophagus, lung and heart percentage (LHP = 100×LHW/SW), head percentage (HP = 100×HW/SW), drip loss percentage (DLP = 100×(HCW − CCW)/HCW), dissectible fat percentage (DFaP = 100×DFaW/RCW), fore legs percentage (FLP = 100×FLW/RCW), thoracic cage

percentage (TCP = 100×TW/RCW), intermediate part percentage (IPP = 100×IPW/RCW), hind part percentage (HPP = 100×HPW/RCW) and meat/bone ratio (M/B = MHLW/BHLW) from a dissected hind leg.

2.4. Meat quality variables

- pH in the muscles *Biceps femoris* (pHBf) and *Longissimus dorsi* was measured at the level of the 5th lumbar vertebra in the chilled carcass. A Crisson MicropH 2001 (Crison Instruments, Barcelona, Spain) with a combined electrode, penetrating 3 mm, was employed.
- Colour measurements were taken on the carcass surface of the *M. Longissimus dorsi* at the level of the 4th lumbar vertebra (CLD and LLD), on the *M. Longissimus dorsi* at the 1st lumbar vertebra cut (CM and LM), and on the perirenal fat (CPFa and LPFa). Colour was recorded using a CR-300 Minolta Chromameter (Minolta Camera Co., Osaka, Japan) which, at each point, gives the average of three measurement of lightness (L^*), redness (a^*) and yellowness (b^*). From these values we calculated Chroma [quantity of colour, $C^* = (a^2 + b^2)^{1/2}$].
- Chemical composition of the meat of a hind leg was determined. Protein percentage (PrHL), fat percentage (FaHL) and moisture percentage (MoHL) were estimated by NIR spectroscopy (Pla, 1996).
- Water holding capacity (WHC) of the *M. Longissimus dorsi* was measured following the Grau and Hamm method (Hamm, 1986), and expressed as the ratio (×100) of muscle area to total wet area.
- Cooking loss (CL) was evaluated by cooking the *M. Longissimus dorsi* in an electric oven at 200°C for 30 min, followed by weighing. CL is the ratio (×100) of the difference in weight between the cooked and raw muscle relative to the weight of the raw muscle. Time before weighing was also 30 min. Water holding capacity of this cooked meat (WHCc) was the WHC of 300 ± 5 mg of cooked meat, determined as described above.

2.5. Statistical model and inference

The small number of males and females in the C group makes it sensible to use statistical methods that are capable of leading to exact small sample inference. Also, it is important to take into account genetic relationships between animals. If these are ignored, the precision of the analysis can be overstated. The linear model assumed was:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{e}$$

where $\mathbf{y}$ is the data vector (traits were analysed separately, in a set of univariate analyses), $\mathbf{b}$ is a random vector including group and sex effects and slaughter weight as a covariate, $\mathbf{a}$ is a vector of individual additive genetic values of animals, $\mathbf{e}$ is a vector of random residuals, and $\mathbf{X}$ and $\mathbf{Z}$ are known incidence matrices relating $\mathbf{b}$ and $\mathbf{a}$ to $\mathbf{y}$, respectively. Data were assumed to be generated from the following normal distribution:

$$\mathbf{y} \mid \mathbf{b}, \mathbf{a}, \sigma_e^2 \sim N(\mathbf{Xb} + \mathbf{Za}, \mathbf{I}\sigma_e^2)$$

where σ_e^2 is a strictly positive scalar representing the unknown variance of random residuals, and $\mathbf{I}$ is an identity matrix.

A Bayesian framework was adopted for inference (Box & Tiao, 1973), thus necessitating an assignment of a prior probability distribution to all unknowns. The prior distribution of additive genetic values was:

$$\mathbf{a} \mid \mathbf{A}, \sigma_a^2 \sim N(\mathbf{0}, \mathbf{A}\sigma_a^2)$$

where $\mathbf{A}$ is the known additive genetic relationship matrix, $\mathbf{0}$ is a vector of zeros and σ_a^2 is the unknown additive genetic variance in the base population. Uniform prior distributions were assumed for fixed effects ($\mathbf{b}$) and variance components, to convey lack of information about these parameters. The prior densities were:

$$p(\mathbf{b}) \sim \text{constant} \qquad p(\sigma_a^2) \sim \text{constant}$$

$$p(\sigma_e^2) \sim \text{constant}$$

Parameter vectors $\mathbf{a}$ and $\mathbf{b}$ were assumed to be independent a priori, so the joint prior density was:

$$p(\mathbf{b}, \mathbf{a}, \sigma_a^2, \sigma_e^2 \mid \mathbf{A}) \propto p(\mathbf{b})p(\mathbf{a} \mid \mathbf{A}, \sigma_a^2)p(\sigma_a^2)p(\sigma_e^2)$$

In a Bayesian analysis, inferences are based on marginal posterior distributions of parameters of interest. The probability calculus takes into account uncertainty about all other parameters, which is either not possible or difficult using classical statistics. The joint posterior distribution of all parameters was then:

$$p(\mathbf{b}, \mathbf{a}, \sigma_a^2, \sigma_e^2 \mid \mathbf{A}, \mathbf{y}) \propto p(\mathbf{y} \mid \mathbf{b}, \mathbf{a}, \sigma_a^2, \sigma_e^2)p(\mathbf{b}, \mathbf{a}, \sigma_a^2, \sigma_e^2 \mid \mathbf{A})$$

$$\propto p(\mathbf{y} \mid \mathbf{b}, \mathbf{a}, \sigma_a^2, \sigma_e^2)p(\mathbf{b})p(\mathbf{a} \mid \mathbf{A}, \sigma_a^2)p(\sigma_a^2)p(\sigma_e^2)$$

The marginal posterior distributions are obtained from the joint posterior density of all unknowns by integrating out all nuisance parameters. The Gibbs sampler algorithm was used to estimate the marginal posterior distributions of fixed effects and variance components (Gelfand & Smith, 1990). Details about

this technique and the development of the fully conditional posterior distributions needed for its implementation can be found in Wang, Rutledge and Gianola (1994) and Sorensen, Wang, Jensen and Gianola (1994).

Samples from the marginal posterior distribution of the difference between effects of selected and control groups were obtained from the samples of the marginal posterior distribution with density $p(\mathbf{b} \mid \mathbf{y})$ as follows:

$$q_i = b_{c,i} - b_{s,i} \quad i = 1, 2, ..., m$$

where $b_{s,i}$ and $b_{c,i}$ are random samples from the marginal distributions of b_s and b_c, corresponding to the two levels of the group (S and C rabbits) in the vector $\mathbf{b}$; m is the number of Gibbs samples drawn.

After some exploratory analysis, the implementation of the Gibbs sampler was made using a single long chain of 120 000 iterations. The first 20 000 iterations (warm up) of each chain were discarded, and samples of the parameter of interest were saved each 20 iterations. The number of saved samples per chain was then 100 000/20 = 5000. Gibbs samples were used directly to estimate features of the marginal posterior distribution (i.e. mean, standard deviation, posterior credibility regions of size 95%, and the probability of a positive difference for contrasts between S and C groups). The method of Johnson (1996), based on coupling chains, was used to assess convergence. The autocorrelation between samples, the Monte Carlo error and the effective chain size were calculated using methods described by Geyer (1992).

3. Results and discussion

Table 2 shows descriptive statistics (mean, standard deviation and coefficient of variation) of the traits analysed across animals. In Spain, light carcasses are demanded. Live slaughter weight and chilled carcass weight averaged 2180 and 1232 g, respectively. All fat deposits and colour measurements had large coefficients of variation. Table 3 gives estimates of the posterior mean and standard deviation of the C and S groups for live weights at 4 and 9 weeks of age (weaning and slaughter times, respectively) and for the daily gain (which was the selection criterion). Two analyses, one estimating the variance components from the data at hand and another using variance components from estimates obtained with a larger data base, gave similar results. Selection for growth rate was successful. The S−C contrast exceeded its posterior standard deviation by more than 3 times; growth rate increased by selection by 9.3%, suggesting a rate of genetic improvement close to 1.5% of the mean per generation. The consequence of this response is a reduction of the age at slaughter, because slaughter weight (SW) is fixed by the market. There was a positive correlated responses for SW, but the genetic change in weaning weight (WW) was not significant, suggesting a nil genetic correlation between WW and DG.

The marginal posterior distributions of the difference between groups S and C for the most important traits

Table 2
Descriptive statistics of the traits analysed[a,b]

Trait	Mean	s.d.	c.v.
CCW (g)	1232	172	13.98
RCW (g)	994	148	14.83
DoP (%)	56.43	2.40	4.26
FGTW (g)	446	63	14.16
HP (%)	8.51	0.64	7.51
LvP (%)	7.14	1.10	15.36
KiP (%)	1.20	0.10	8.68
LHP (%)	2.53	0.29	11.41
FLP (%)	16.55	0.61	3.70
TCP (%)	11.95	1.00	8.36
IPP (%)	30.53	1.14	3.75
HPP (%)	37.27	1.62	4.36
SFaW (g)	6.61	2.41	36.52
PFaW (g)	12.76	5.12	40.31
IfaW (g)	13.94	4.80	34.43
DFaP (%)	3.29	0.77	23.29
M/B	5.03	0.57	11.40
MHLW (g)	137.28	20.95	15.26
BHLW (g)	27.33	2.98	10.89
CLD	3.73	0.97	25.98
LLD	54.41	1.93	3.55
CPFa	8.37	1.81	21.61
LPFa	68.17	2.04	2.99
pHLD	5.70	0.16	2.88
pHBF	5.83	0.16	2.69
WHC (%)	33.83	3.05	9.02
CL (%)	33.88	7.25	21.40
WHCc (%)	19.40	3.49	18.00
CM	5.00	1.11	22.15
LM	51.67	1.79	3.47
FaHL (%)	4.16	0.68	16.40
PrHL (%)	21.13	0.32	1.53
MoHL (%)	73.91	0.80	1.08

[a] CCW, chilled carcass weight; RCW, reference carcass weight; DoP, dressing out percentage; FGTW, full gastrointestinal tract weight; HP, head percentage; LvP, liver percentage; KiP, kidneys percentage; LHP, set of organs consisting of thymus, trachea, oesophagus, lung and heart percentage; FLP, fore legs percentage; TCP, thoracic cage percentage; IPP, intermediate part percentage; HPP, hind part percentage; SFaW, scapular fat weight; PFaW, perirenal fat weight; IFaW, inguinal fat weight; DFaP, disectible fat percentage; M/B, meat/bone ratio from a dissected hind leg; MHLW, meat weight of a hind leg; BHLW, bone weight of a hind leg; CLD, chroma of the *M. Longissimus dorsi*; LLD, lightness of the *M. Longissimus dorsi*; CPFa, chroma of the perirenal fat; LPFa, lightness of the perirenal fat; pHLD, muscular pH of the *M. Longissimus dorsi*; pHBF, muscular pH of the *M. Biceps femoris*; WHC, water holding capacity of the *M. Longissimus dorsi*; CL, cooking loss of the *M. Longissimus dorsi*; WHCc, water holding capacity of the cooked *M. Longissimus dorsi*; CM, chroma of the meat; LM, lightness of the meat; FaHL, fat percentage of the hind leg; PrHL, protein percentage of the hind leg; MoHL, moisture percentage of the hind leg.

[b] S.d., standard deviation; c.v., coefficient of variation. pH measurement of the *M. Longissimus dorsi* taken at the level of the 5th lumbar vertebra on the chilled carcass. Colours measurements of the *M. Longissimus dorsi* taken on the carcass surface at the level of the 4th lumbar vertebra and colour measurements of the meat taken on the *M. Longissimus dorsi* at the 1st lumbar vertebra cut.

Table 3
Means and standard deviations (in brackets) of the posterior distributions of the effects of group C, S and of their difference[a]

Trait	C	S	S−C
WW (g)	574 (26)	607 (22)	33 (32)
SW (g)	2159 (56)	2337 (47)	178 (67)
DG (g/d)	45.3 (1.10)	49.5 (0.91)	4.22 (1.33)

[a] WW, body weight at 4 weeks; SW, body weight at 9 weeks; DG, daily gain.

are presented in Fig. 1, and the marginal posterior distribution of the differences between females and males in Fig. 2. All these distributions were nearly unimodal and symmetric about their modes; the values of the mean, mode and median were very similar.

Table 4 shows the summary statistics of the estimated marginal posterior distributions of the differences between groups (S−C) for several organ and slaughter traits. Table 5 shows corresponding statistics for the differences between sexes for the same traits. Selected animals had a higher development of liver (0.38%),

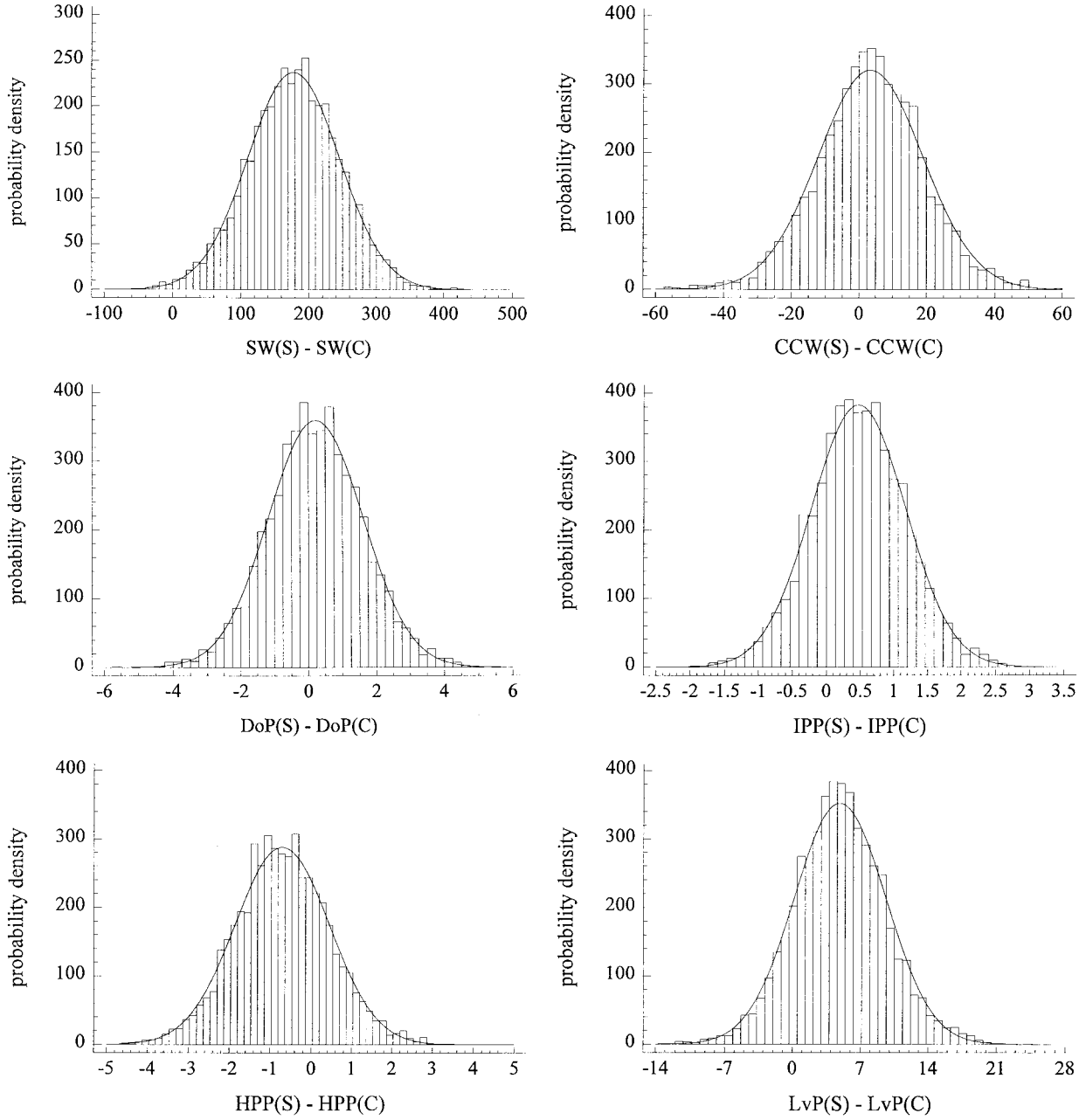

Fig. 1. Marginal posterior density of the differences between selected group (S) and control group (C) for carcass traits: slaughter weight (SW), chilled carcass weight (CCW), dressing out percentage (DoP), intermediate part percentage (IPP), hind part percentage (HPP), liver percentage (LvP). Weights in grams.

kidneys (0.04%) and of the set of organs consisting of the thymus, trachea, oesophagus, lung and heart (0.12%) relative to the control group, indicating a lower degree of maturity at slaughter. However, these differences cannot be claimed to differ from 0. The trends observed agree with results of Pla et al. (1996, 1998) and Gómez, Feki and Baselga (1993) comparing breeds of different adult weight slaughtered at the same weight. However, the differences found by these authors could be due not only to differences in growth, but to the different genetic origin of the breeds. No differences were found in carcass yield. No differences between males and females were found (Table 5), which agrees with results obtained by López, Sierra and Lite (1992) in Gigante de España rabbits and by Parigi-Bini, Xiccato, Cinetto, DalleZotte and Converso (1992) with commercial hybrids.

The recent development of a market for retail cuts has led to a strong commercial interest in carcass composition. Table 6 displays summary statistics of the estimated marginal posterior distributions of the differences between S and C groups for several carcass quality

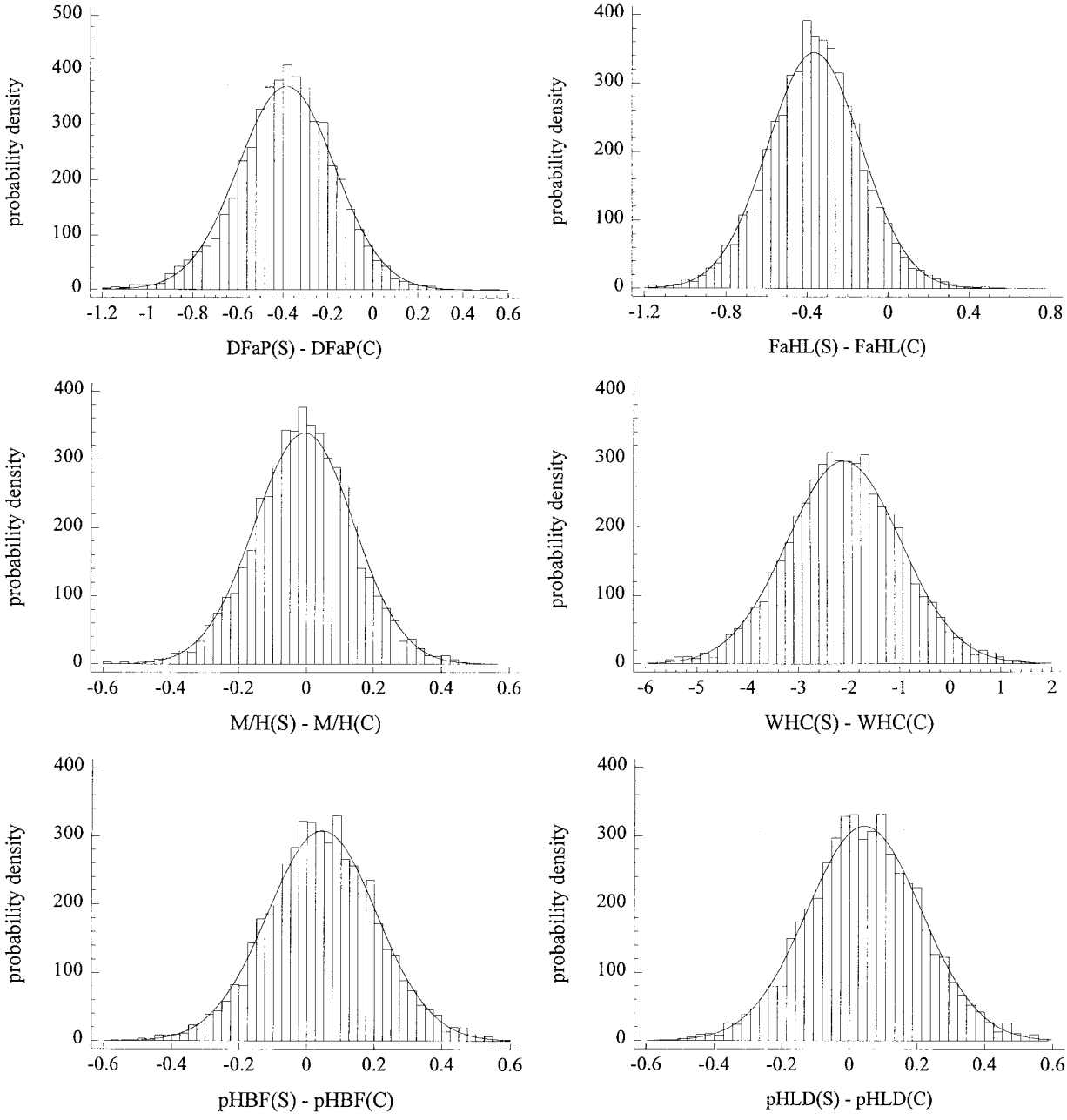

Fig. 2. Marginal posterior density of the differences between selected group (S) and control group (C) for tissue composition of the carcass and meat quality traits: dissectible fat percentage (DFaP), fat percentage of a hind leg (FaHL), meat/bone ratio of a hind leg (M/B), water holding capacity (WHC), pH of the *M. Biceps femoris* (pHBF) and pH of the *M. Longissimus dorsi* (pHLD).

Table 4
Summary statistics of the estimated marginal posterior distributions of the differences between selected and control groups for several organ and slaughter traits[a,b]

Trait	PM	PSD	PD95%	$P>0$
CCW (g)	3.41	15.61	−27.76, 34.71	0.60
RCW (g)	−3.88	15.97	−35.66, 28.14	0.40
DoP (%)	0.21	1.39	−0.92, 0.96	0.55
FGTW (g)	−6.22	17.05	−38.91, 29.99	0.34
HP (%)	−0.00629	0.341	−0.69, 0.68	0.49
LvP (%)	0.375	0.378	−0.35, 1.14	0.85
KiP (%)	0.0419	0.0445	−0.045, 0.132	0.83
LHP (%)	0.118	0.114	−0.105, 0.348	0.85

[a] Mean (PM), standard deviation (PSD), symmetric density region at 95% (PD95%) and probability of a positive difference ($P>0$) from the marginal posterior density.

[b] CCW, chilled carcass weight; RCW, reference carcass weight; DoP, dressing out percentage; FGTW, full gastrointestinal tract weight; HP, head percentage; LvP, liver percentage; KiP, kidneys percentage; LHP, set of organs consisting of the thymus, trachea, oesophagus, lung and heart percentage.

Table 5
Summary statistics of the estimated marginal posterior distributions of the differences between females and males for several organ and slaughter traits[a,b]

Trait	PM	PSD	PD95%	$P>0$
CCW (g)	−3.63	10.27	−23.564, 16.467	0.36
RCW (g)	−0.127	10.75	−20.942, 20.843	0.50
DoP (%)	−0.163	1.18	−2.449, 2.117	0.44
FGTW (g)	−7.73	10.49	−28.370, 12.696	0.23
HP (%)	−0.138	0.292	−0.705, 0.428	0.32
LvP (%)	0.040	0.278	−0.500, 0.575	0.56
KiP (%)	−0.0057	0.037	−0.077, 0.066	0.44
LHP (%)	0.022	0.092	−0.157, 0.200	0.60

[a] Mean (PM), standard deviation (PSD), symmetric density region at 95% (PD95%) and probability of a positive difference ($P>0$) from the marginal posterior density.

[b] CCW, chilled carcass weight; RCW, reference carcass weight; DoP, dressing out percentage; FGTW, full gastrointestinal tract weight; HP, head percentage; LvP, liver percentage; KiP, kidneys percentage; LHP, set of organs consisting of the thymus, trachea, oesophagus, lung and heart percentage.

traits, and Table 7 shows similar statistics for the marginal posterior distributions of the differences between sexes. The lower degree of maturity at slaughter weight of the S animals did not lead to appreciable changes in most carcass composition and quality traits. However, a lower content in dissectible fat weights in S animals than in C animals was detected: −0.31 g for scapular fat, −1.62 g for perirenal fat and −2.03 g for inguinal fat, plus a lower content (−0.39%) in dissectible fat percentage of the "Reference" carcass (Table 6). This may be because fat tissue has a late development (Cantier, Vezinhet, Rouvier & Dauzier, 1969; Deltoro & López, 1985). In fact, Ouhayoun (1989) and Pla et al. (1996) found differences in fat content of the hind leg

Table 6
Summary statistics of the estimated marginal posterior distributions of the differences between selected and control groups for several carcass quality traits[a,b]

Trait	Mean	PSD	PD95%	$P>0$
FLP (%)	0.020	0.473	−0.916, 0.958	0.51
TCP (%)	0.265	0.915	−1.55, 2.08	0.61
IPP (%)	0.479	0.695	−0.897, 1.860	0.76
HPP (%)	−0.702	1.156	−2.98, 1.63	0.27
SFaW (g)	−0.310	0.673	−1.647, 1.036	0.32
PFaW (g)	−1.616	1.136	−3.881, 0.621	0.07
IfaW (g)	−2.025	1.016	−4.044, -0.00048	0.03
DFaP (%)	−0.394	0.217	−0.837, 0.0427	0.03
M/B	−0.00632	0.147	−0.297, 0.292	0.48
MHLW (g)	−3.252	2.330	−7.740, 1.490	0.08
BHLW (g)	−0.707	0.797	−2.279, 0.934	0.18
CLD	0.127	0.302	−0.475, 0.724	0.67
LLD	−1.269	1.484	−4.196, 1.692	0.19
CPFa	−0.697	0.585	−1.858, 0.494	0.11
LPFa	0.684	1.802	−2.878, 4.325	0.65

[a] Mean (PM), standard deviation (PSD), symmetric density region at 95% (PD95%) and probability of a positive difference ($P>0$) from the marginal posterior density.

[b] FLP, fore legs percentage; TCP, thoracic cage percentage; IPP, intermediate part percentage; HPP, hind part percentage; SFaW, scapular fat weight; PFaW, perirenal fat weight; IFaW, inguinal fat weight; DFaP, disectible fat percentage; M/B, meat/bone ratio from a dissected hind leg; MHLW, meat weight of a hind leg; BHLW, bone weight of a hind leg; CLD, chroma of the *M. Longissimus dorsi*; LLD, lightness of the *M. Longissimus dorsi*; CPFa, chroma of the perirenal fat; LPFa, lightness of the perirenal fat. Colours measurements of the *M. Longissimus dorsi* taken on the carcass surface at the level of the 4th lumbar vertebra.

when comparing breeds of different size at the same slaughter age. They observed that large sized breeds had lower fat contents than small ones. The absolute value of these differences is small, although the amount of dissectible fat in rabbit carcasses is generally very small (3.29% of the "Reference" carcass weight, on average). Carcasses from females had more dissectible fat at slaughter weight than male carcasses: 0.26 g for scapular fat, 1.02 g for perirenal fat and 1.10 g for inguinal fat, and 0.24% for total dissectible fat percentage of the "Reference" carcass. No differences were observed in the rest of the traits. López et al. (1992) found that male carcasses had a higher quantity of total fat (intermuscular + subcutaneus + pelvic + renal) than females in Gigante de España rabbits, but no differences were found by Pla et al. (1998) with animals having the same genetic type as those in the present experiment, and López and Deltoro (1984). The results found by López et al. could be explained if the differences in adult weight between males and females were much higher in Gigante de España rabbits than in our line, so females would be much less mature at slaughter weight than males in that breed. The lower degree of maturity could compensate the known effect of sex on tissue composition which favours the development of adipose tissue in females.

C animals had a higher content of meat (−3.25 g) and bone (−0.71 g) of the hind leg than S rabbits. However, the meat to bone ratio, which is the best predictor of the carcass M/B ratio (Hernández, Pla & Blasco, 1996), was not affected by selection.

Table 8 shows the summary statistics of the estimated marginal posterior distributions of the differences between S and C groups for several meat quality traits. Table 9 gives the corresponding statistics for the difference between sexes for these traits. There was not a clear effect of selection on most traits. There was a decrease (−0.37%) in the content in fat of the hind leg, in the same direction as for the dissectible fat, and a decrease (−2.10%) in water holding capacity in S animals, which could be related to their higher fat content. Cooking loss and water holding capacity of the cooked meat were higher in meat from selected animals (3.31 and 2.17%, respectively). Differences between sexes were not observed.

Selection for increased growth rate is interesting economically because it improves the food conversion ratio (Torres, Baselga & Gómez, 1992). However, it has the undesirable effect of increasing adult body weight, leading to less mature animals at the same slaughter weight. As a consequence, a slight reduction in fat content of the carcasses and meat, a higher development of liver, kidneys and set of organs consisting of thymus, trachea, oesophagus, lung and heart, and a reduction in water

Table 7
Summary statistics of the estimated marginal posterior distributions of the differences between females and males for several carcass quality traits[a,b]

Trait	Mean	PSD	PD95%	$P>0$
FLP (%)	−0.020	0.404	−0.804, 0.762	0.48
TCP (%)	−0.308	0.783	−1.825, 1.209	0.35
IPP (%)	0.141	0.589	−0.999, 1.279	0.60
HPP (%)	0.014	0.984	−1.897, 1.925	0.51
SFaW (g)	0.260	0.399	−0.515, 1.040	0.74
PFaW (g)	1.022	0.826	−0.568, 2.631	0.89
IfaW (g)	1.097	0.696	−0.248, 2.459	0.94
DFaP (%)	0.238	0.128	−0.0087, 0.485	0.97
M/B	0.069	0.102	−0.128, 0.265	0.48
MHLW (g)	−0.697	1.659	−3.888, 2.527	0.34
BHLW (g)	−0.466	0.471	−1.390, 0.459	0.16
CLD	0.031	0.218	−0.393, 0.451	0.56
LLD	−0.340	1.264	−2.786, 2.104	0.40
CPFa	−0.012	0.430	−0.859, 0.821	0.49
LPFa	−0.030	1.616	−3.226, 3.073	0.49

[a] Mean (PM), standard deviation (PSD), symmetric density region at 95% (PD95%) and probability of a positive difference ($P>0$) from the marginal posterior density.

[b] FLP, fore legs percentage; TCP, thoracic cage percentage; IPP, intermediate part percentage; HPP, hind part percentage; SFaW, scapular fat weight; PFaW, perirenal fat weight; IFaW, inguinal fat weight; DFaP, disectible fat percentage; M/B, meat/bone ratio from a dissected hind leg; MHLW, meat weight of a hind leg; BHLW, bone weight of a hind leg; CLD, chroma of the *M. Longissimus dorsi*; LLD, lightness of the *M. Longissimus dorsi*; CPFa, chroma of the perirenal fat; LPFa, lightness of the perirenal fat. Colours measurements of the *M. Longissimus dorsi* taken on the carcass surface at the level of the 4th lumbar vertebra.

Table 8
Summary statistics of the estimated marginal posterior distributions of the differences between selected and control groups for several meat quality traits[a,b,c]

Trait	PM	PSD	PD95%	$P>0$
pHLD	0.044	0.169	−0.294, 0.382	0.60
pHBF	0.045	0.162	−0.277, 0.369	0.61
WHC (%)	−2.098	1.121	−−4.305, 0.144	0.03
CL (%)	3.313	2.485	−1.621, 8.148	0.92
WHCc (%)	2.174	1.089	−0.037, 4.363	0.97
CM	−0.178	0.337	−0.844, 0.495	0.29
LM	−0.285	1.527	−3.323, 2.791	0.42
FaHL (%)	−0.365	0.232	−0.825, 0.093	0.05
PrHL (%)	0.136	0.541	−0.945, 1.222	0.59
MoHL (%)	0.0669	2.000	−3.918, 4.079	0.51

[a] Mean (PM), standard deviation (PSD), symmetric density region at 95% (PD95%) and probability of a positive difference ($P>0$) from the marginal posterior density.

[b] pHLD, muscular pH of the *M. Longissimus dorsi*; pHBF, muscular pH of the *M. Biceps femoris*; WHC, water holding capacity of the *M. Longissimus dorsi*; CL, cooking loss of the *M. Longissimus dorsi*; WHCc, water holding capacity of the cooked *M. Longissimus dorsi*; CM, chroma of the meat; LM, lightness of the meat; FaHL, fat percentage of the hind leg; PrHL, protein percentage of the hind leg; MoHL, moisture percentage of the hind leg.

[c] pH measurement of the *M. Longissimus dorsi* taken at the level of the 5th lumbar vertebra on the chilled carcass. Colour measurements of the meat taken on the *M. Longissimus dorsi* at the 1st lumbar vertebra cut.

Table 9
Summary statistics of the estimated marginal posterior distributions of the differences between females and males for several meat quality traits[a,b,c]

Trait	PM	PSD	PD95%	$P>0$
pHLD	0.0342	0.145	−0.247, 0.316	0.60
pHBF	0.0425	0.139	−0.227, 0.312	0.62
WHC (%)	0.548	0.904	−1.200, 2.293	0.73
CL (%)	−1.329	1.983	−5.258, 2.467	0.25
WHCc (%)	0.208	0.881	−1.514, 1.912	0.60
CM	−0.347	0.235	−0.805, 0.108	0.07
LM	−0.464	1.367	−3.155, 2.150	0.36
FaHL (%)	0.057	0.143	−0.222, 0.337	0.66
PrHL (%)	−0.013	0.466	−0.917, 0.888	0.49
MoHL (%)	0.050	1.725	−3.297, 3.389	0.51

[a] Mean (PM), standard deviation (PSD), symmetric density region at 95% (PD95%) and probability of a positive difference ($P>0$) from the marginal posterior density.

[b] pHLD, muscular pH of the *M. Longissimus dorsi*; pHBF, muscular pH of the *M. Biceps femoris*; WHC, water holding capacity of the *M. Longissimus dorsi*; CL, cooking loss of the *M. Longissimus dorsi*; WHCc, water holding capacity of the cooked *M. Longissimus dorsi*; CM, chroma of the meat; LM, lightness of the meat; FaHL, fat percentage of the hind leg; PrHL, protein percentage of the hind leg; MoHL, moisture percentage of the hind leg.

[c] pH measurement of the *M. Longissimus dorsi* taken at the level of the 5th lumbar vertebra on the chilled carcass. Colour measurements of the meat taken on the *M. Longissimus dorsi* at the 1st lumbar vertebra cut.

holding capacity of the raw meat should be expected. From our study, it can be concluded that there are no apparently important negative effects of selection for increased growth rate on carcass and meat quality. However, the difficulty of obtained detailed data, such as presented here, makes it difficult to study the correlated effects of selection with high precision.

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