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EFFECT OF FEED RESTRICTION AND FEEDING PLANS ON PERFORMANCE, SLAUGHTER TRAITS AND BODY COMPOSITION OF GROWING RABBITS

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Abstract: Two feeding systems (L, *ad libitum vs.* R, feed restriction) were combined with 3 feeding plans (MM, MH, HH) to evaluate the effects on performance, slaughter results, body composition and nitrogen balance of 300 commercial crossbred rabbits kept individually from weaning to slaughter (34-70 d of age). The R rabbits were fed from 80% (first days on trial) to 100% (end of 3rd wk) of *ad libitum* intake, whereafter R rabbits had free access to feed. The 3 feeding plans were: MM plan, M diet with moderate digestible energy (DE) content, 10.6 MJ/kg, throughout the trial; HH plan, H diet with high DE content, 11.1 MJ/kg, throughout the trial; MH plan, M diet for the first 3 wk and H diet for the last 2 wk. Feed restriction did not affect nutrient digestibility, growth rate on the whole trial and slaughter results, but improved feed conversion (2.96 *vs.* 2.89 in L and R rabbits, respectively; $P<0.01$) and reduced N excretion (2.16 *vs.* 2.07 g excreted N/d, in L and R rabbits; $P<0.05$). At the end of the first period (55 d), R rabbits showed lower empty body protein, lipid, and gross energy gains than L rabbits, but differences disappeared within the end of the trial. The HH plan improved feed conversion (2.97 *vs.* 2.89 for MM *vs.* HH; $P<0.05$), but increased excreted N (2.03 *vs.* 2.17 g/d; $P<0.001$) in comparison with the MM plan due to the higher digestible protein/DE ratio of H diet, whereas the MH plan showed intermediate results. In conclusion, a moderate feed restriction during post weaning improved feed conversion and reduced N excretion without negative effects on growth or slaughter results. Moreover, N excretion was confirmed to depend largely on dietary nitrogen content.

Key Words: feed restriction, feeding plans, growth performance, body composition, nitrogen excretion, rabbit.

INTRODUCTION

On intensive farms, commercial crossbred rabbits selected for high growth rate and feed intake are largely used. Thus, growing rabbits are usually fed *ad libitum* to maximise performance (Maertens, 2010), but in some countries (France and Italy) feed restriction is often applied during post–weaning to reduce daily changes in feed intake and the possible negative consequences on digestive health and epizootic rabbit enteropathy (ERE) occurrence (Boisot *et al.,* 2003; Szendrő *et al.,* 2008; Gidenne and Feugier, 2009; Gidenne *et al.,* 2012; Maertens and Gidenne, 2016). To this end, severe feed restriction rates (60% to 80% of the *ad libitum* feeding) during the first 3 or 4 wk after weaning are used, which may however impair final live weights, slaughter yields, and body composition (Xiccato, 1999; Gidenne *et al.,* 2009a). In fact, feed restriction may not prevent large changes in individual feed intake when rabbits are housed collectively and restricted on a quantitative base (Gidenne *et al.,* 2009a; Knudsen *et al.,* 2014), or when housed individually and restricted on the base of the access time to feeders (Romero *et al.,* 2010). Differently, even a mild feed restriction (93% of *ad libitum*) during the first period may improve rabbit health status without impairing

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growth performance, slaughter results and carcass traits in rabbits housed individually and submitted to quantitative feed restriction (Birolo *et al.,* 2016).

High digestible energy (DE) diets are also currently used during fattening to optimise feed conversion (Maertens, 2010), whereas low-DE diets are usually fed during post weaning to reduce the risk of enteric diseases (Gidenne *et al.,* 2010; Maertens and Gidenne, 2016). However, when a suitable fibre supply is guaranteed in terms of quantity and quality, high-DE diets may be successfully fed even after weaning with positive effects on feed efficiency and body nitrogen balance (Trocino *et al.,* 2011 and 2013; Xiccato *et al.,* 2011; Tazzoli *et al.,* 2015).

When a suitable fibre supply is provided, the combined use of feed restriction and high-DE diets may result in synergistic positive effects, as outlined in growing rabbits housed collectively and submitted to rather severe feed restriction (75% of *ad libitum* level) (Knudsen *et al.,* 2014).

Accordingly, the aim of the present study was to evaluate whether a mild feed restriction rate combined with feeding plans based on diets with different energy content may affect growth performance, slaughter traits, body composition and nitrogen balance in growing rabbits housed individually.

MATERIALS AND METHODS

Animals and experimental conditions

The study was approved by the Ethical Committee for Animal Experimentation of the University of Padova. All animals were handled following the principles stated by the EC Directive 86/609/EEC regarding the protection of animals used for experimental and other scientific purposes.

The trial ran at the rabbit farm of the University of Padova, in a closed shed during the months of April and June under a natural photoperiod. Extraction fans and automatic heating system were used to control air circulation and maintain the temperature within 18-23°C.

A total of 300 rabbits (Hypharm, Groupe Grimaud, Roussay, France) were moved from a commercial farm to the experimental facilities; 12 rabbits were immediately slaughtered to measure initial empty body weight and composition by comparative slaughter technique (Xiccato *et al.,* 2003); the other 288 rabbits were put in individual cages (285×410×285 mm), randomly allocated to 6 experimental groups (48 animals per group), homogeneous by live weight (LW) and variability, according to a bi–factorial arrangement, i.e. 2 feeding systems (L, *ad libitum vs.* R, feed restriction) and 3 feeding plans (MM *vs.* MH *vs.* HH) based on the administration of 2 diets with moderate (M diet; DE: 10.6 MJ/kg) or high (H diet; DE: 11.1 MJ/kg) digestible energy content. Rabbits were controlled from 34 d of age to commercial slaughter (70 d).

Diets, feeding plans and feed restriction

Two experimental diets were formulated and pelleted to 3.5 mm of diameter and 10-11 mm of length; their ingredients and chemical composition are listed in Table 1. The diets were formulated to satisfy rabbits requirements during post–weaning and fattening according to De Blas and Mateos (2010) and were supplemented with synthetic lysine and methionine, vitamins, macro- and micro-minerals. The diets were not supplemented with antibiotic or coccidiostatic. The M diet presented 15.5% crude protein (CP), 34.4% neutral degergent fibre (NDF), 18.5% acid detergent fibre (ADF), 12.6% starch; the H diet contained 16.6% CP, 32.0% aNDF, 17.3% ADF, 13.8% starch (Table 1).

The 3 feeding plans consisted of MM plan, where rabbits were fed M diet during the whole trial (5 wk); HH plan, H diet also throughout the trial (5 wk); MH plan, M diet for the first 3 wk and H diet in the last 2 wk (re-feeding period). Within the feeding plan, half of the rabbits were fed *ad libitum* (L group) throughout the trial and half received a restricted amount of diet (R group) for the first 3 wk; all rabbits were fed *ad libitum* in the last 2 wk of trial. Two theoretical feed intake curves were calculated on the basis of previous studies of the research team with the same commercial crossbreed and differentiated according to the DE levels of the experimental diets. The theoretical feed restriction rate averaged 90% and ranged from 80% to 100% of the theoretical *ad libitum* intake from the beginning of the trial until the end of the 3rd wk. The quantity of feed offered daily to the R rabbits during the restriction period was not corrected according to the measured feed intake of L rabbits.

Growth performance and health status

Individual live weights were recorded twice a week and individual feed intakes and health status were controlled daily. During the trial, and mainly in the first weeks, 17 animals died belonging to the different groups, in detail: 3 rabbits from group L–MM, 3 from group L–MH, 4 from group L–HH, 2 from group R–MM, 1 from group R–MH and 4 from group R–HH. In most cases, rabbits showed digestive problems, with symptoms which were ascribed to ERE (Marlier *et al.,* 2003).

In order to control illness and maintain mortality within acceptable rates in view of the scientific aims of the trial, the rabbits received an antibiotic treatment (Tiamuline 12.5%, Tiamvet, CEVA Santé Animal, France) in water from 40 to 49 d of age.

Digestibility trials

The nutrient apparent digestibility and the nutritive value of diets were measured during an *in vivo* digestibility assay performed according to the European standardised method (Perez *et al.,* 1995). The trial was carried out on 48 rabbits from 47 to 51 d of age. Within dietary treatment (M diet or H diet), half rabbits were fed *ad libitum*, while the others were restricted according to the previewed feeding curves.

Table 1: Ingredients and chemical composition (% as fed) of the experimental diets.

	Diet M	Diet H
Ingredients		
Dehydrated alfalfa meal (16% CP)	34.00	24.55
Wheat bran	24.00	20.00
Barley	12.00	20.00
Dried beet pulp	16.00	14.50
Soybean meal (47% CP)	5.00	8.00
Sunflower meal (29% CP)	5.00	8.00
Soybean oil	1.00	1.50
Molasses	1.50	1.50
Calcium carbonate	0.25	0.48
Dicalcium phosphate	0.28	0.50
Sodium chloride	0.40	0.40
Llysine	0.05	0.05
DLmethionine	0.05	0.05
Vitamin mineral premix*	0.47	0.47
Chemical composition		
Dry matter (%)	89.4	88.9
Crude protein (CP, %)	15.5	16.6
Ether extract (%)	3.5	4.3
Crude fibre (%)	15.1	14.5
Neutral detergent fibre (%)	34.4	32.0
Acid detergent fibre (%)	18.5	17.3
Lignin (%)	4.3	4.1
Starch (%)	12.6	13.8
Gross energy (MJ/kg)	16.7	16.8

*Premix provided per kg of complete diet: vitamin A, 12000 UI; vitamin D3, 1000 UI; vitamin E acetate, 50 mg; vitamin K3, 2 mg; biotin, 0.1 mg; thiamine, 2 mg; riboflavin, 4 mg; vitamin B6, 2 mg; vitamin B12, 0.1 mg; niacin, 40 mg; pantothenic acid, 12 mg; folic acid, 1 mg; Fe, 100 mg; Cu, 20 mg; Mn, 50 mg; Co, 2 mg; I, 1 mg; Zn, 100 mg; Se, 0.1 mg.

Comparative slaughters, body composition and nitrogen balance

Three comparative slaughters were performed to measure initial (34 d, 12 rabbits), intermediate (55 d of age, end of the restriction period; 36 rabbits, 6 per experimental group), and final (69 d of age; 36 rabbits, 6 per experimental group) empty body (EB) weight and chemical composition (Xiccato *et al.,* 2003).

The EB of the rabbits subjected to comparative slaughter were frozen at –18°C, ground, and freeze-dried. The freeze-dried samples were ground and analysed to determine their chemical composition. Likewise, pools of freeze dried samples were made within the experimental group, with EB of rabbits slaughtered at 55 d (6 pools) and at 69 d (6 pools) to determine their gross energy content.

To calculate the nitrogen (N) balance, the body N content of all animals was estimated at the beginning (34 d of age), at 55 d of age, and at the end of trial (69 d of age) on the basis of the body protein content of rabbits sacrificed in the comparative slaughters. The individual values of ingested N were calculated on the base of individual feed intake and diet N content (16% CP); the retained N was calculated as the difference between the body N content at 69 d and 34 d of age; the excreted N was obtained by subtracting the retained N from the ingested N (ERM/AB-DLO, 1999).

Commercial slaughters and carcass and meat quality recordings

At 70 d, all remaining animals (199 rabbits) were weighed at the experimental farm and transported to a commercial slaughterhouse by an authorised truck (about 1 h of transport). Feeding was suspended 5 h before loading, while water was available until loading. At the slaughterhouse, the rabbits were individually weighed, stunned by electro-anaesthesia and killed by jugulating. After 24-h chilling, commercial carcasses were dissected according to harmonised methods (Blasco and Ouhayoun, 1996).

Chemical analyses

Diets and faeces were analysed to determine the contents of dry matter (934.01), ash (967.05), CP (2001.11), and starch (amyloglucosidase α-amylase method, 996.11; only in diets) using AOAC (2000) methods following harmonised procedures (Gidenne *et al.,* 2001). The ether extract was analysed after acid hydrolysis (EC, 1998). The fibre fractions, aNDF (neutral detergent fibre without sodium sulphite inclusive of residual ash), ADF (acid detergent fibre expressed inclusive of residual ash), and ADL (acid detergent lignin expressed inclusive of residual ash), were analysed according to Mertens (2002), AOAC (2000, 973.187) and Van Soest *et al.* (1991), respectively, using the sequential procedure and the filter bag system (Ankom Technology, Macedon, NY, USA). The gross energy was measured with an adiabatic bomb calorimeter (IKA C200, Staufen, Germany) according to method 9831 (ISO, 1998).

Statistical analyses

The data were analysed by a two-way ANOVA, with feed restriction, feeding plan and their interaction as fixed effects using PROC GLM of SAS (2013). The Bonferroni t-test was used to compare LS means. Difference among LS means with $P<0.05$ were accepted as representing statistically significant differences.

RESULTS AND DISCUSSION

Effect of feed restriction

Studies on feed restriction started a long time ago with the aim of improving feed efficiency and standardising growth curves in rabbits without affecting performance, carcass and meat traits (Xiccato, 1999; Cavani *et al.,* 2009). In the present trial, during the 1st wk feed restriction significantly ($P<0.001$) reduced feed intake (107 *vs.* 93 g/d in L and R groups) and growth rate (53.6 *vs.* 46.8 g/d); during the 2nd wk, feed restriction was less effective on feed intake (134 *vs.* 129 g/d; $P=0.05$) and did not affect growth rate; during the 3rd wk, feed intake was similar (150 g/d) and growth rate was even lower in L rabbits compared to R ones (48.3 *vs.* 51.0 g/d, $P=0.05$) (data not reported in tables). Actually, during the 2nd and 3rd wk of trial the occurrence of digestive troubles reduced the differences in feed intake between L and R rabbits. In the following weeks, growth rate and feed intake did not change according to the feeding level of the previous period. In fact, if the use of a theoretical restriction curve is the easiest solution to apply in the field at farm level, several factors may prevent us from achieving the expected feed restriction rate and thus reduce the effect of feed restriction itself.

Growth performance during the restriction and re-feeding periods and the whole trial are shown in Table 2. In the first 3 wk, feed restriction significantly ($P<0.001$) reduced feed intake (5.6%) and improved feed conversion (3.2%; $P<0.05$) in comparison with *ad libitum* feeding without affecting daily growth (on av. 51.7 g/d). During the re-feeding period, growth performances were not affected by the previous feeding level, whereas feed restriction significantly decreased feed intake (2.9%; $P<0.05$) and improved feed conversion (2.4%; $P=0.01$) on the whole trial in comparison with *ad libitum* feeding, without significant effects on daily weight gain and final LW.

Most studies reported relevant reductions in feed conversion (by 10-15%) with restriction rates at 80-60% of *ad libitum* during post-weaning followed by *ad libitum* re-feeding in the last 2-3 wk before slaughter (Bovera *et al.,* 2013; Knudsen *et al.,* 2014; Maertens and Gidenne, 2016). According to Gidenne *et al.* (2009a), the decrease in feed intake level from 100 to 90, 80, 70 and 60% of *ad libitum* linearly enhanced feed conversion at the expense of daily growth and final LW. Only the mildest feed restriction (90% of *ad libitum*) improved feed conversion (3% compared to

Table 2: Growth performance during the restriction and re-feeding periods and the whole trial (least squares means).

	Feed restriction (R)		Feeding plan (P)			*P*-value			
	ad libitum	Restricted	MM	MH	HH	R	P	R×P	RMSE
Rabbits (n)	116	119	79	80	76				
Initial live weight (g)	950	942	943	943	953	0.63	0.73	0.89	107
Intermediate weight (55 d)	2045	2017	2020	2036	2036	0.29	0.83	0.81	199
Final live weight (g)	2638	2618	2618	2634	2631	0.54	0.91	0.77	256
Feed restriction period (34 to 55 d)									
Weight gain (g/d)	52.2	51.2	51.3	52.2	51.5	0.28	0.71	0.87	7.2
Feed intake (g/d)	131	124	128	129	125	<0.001	0.26	0.86	15
Feed conversion	2.52	2.44	2.53	2.48	2.43	<0.04	0.07	0.58	0.26
Re-feeding period (55 to 70 d)									
Weight gain (g/d)	39.6	40.1	39.9	39.9	39.7	0.63	0.98	0.44	7.7
Feed intake (g/d)	149	149	152	149	147	0.93	0.26	0.87	22
Feed conversion	3.84	3.79	3.90	3.79	3.75	0.42	0.16	0.26	0.52
Whole period (34 to 70 d)									
Weight gain (g/d)	46.9	46.5	46.5	47.0	46.6	0.61	0.83	0.72	5.8
Feed intake (g/d)	139	134	138	137	134	<0.04	0.26	0.99	16
Feed conversion	2.96	2.89	2.97[b]	2.93[ab]	2.89[a]	0.01	<0.03	0.30	0.20

MM, diet with moderate digestible energy during 5 wk; MH, M diet for the first 3 wk and H diet for the last 2 wk. HH, diet with high digestible energy during 5 wk; RMSE: root mean square error.

[a,b]Means with different superscript letters are statistically different ($P<0.05$).

the control group) without worsening growth performance (Gidenne *et al.,* 2009a), as confirmed in other trials (Birolo *et al.,* 2016; present study).

Several authors also reported that feed restriction may increase nutrient digestibility when severe restriction rates (70-80% of *ad libitum* intake) are used (Xiccato *et al.,* 1992; Di Meo *et al.,* 2007; Knudsen *et al.,* 2014). Under our condition, however, feed restriction did not affect nutrient digestibility coefficients (Table 3), as also found by Birolo *et al.* (2016) in rabbits submitted to mild feed restriction rates (93% of *ad libitum* intake). In fact, in the present study, the digestibility trial took place during the 3rd wk when R and L rabbits showed similar feed intake.

Table 3: Digestibility coefficients (least squares means) and nutritive value (as fed) measured in growing rabbits from 47 to 51 d of age[1].

	Feed restriction (R)		Diet (D)		*P*-value			
	ad libitum	Restricted	M	H	R	D	R×D	RMSE
Rabbits (n)	24	24	24	24				
Feed intake (g/d)	144	149	147	146	0.21	0.73	0.41	14
Dry matter (%)	63.9	64.2	62.9	65.1	0.56	<0.001	0.73	1.9
Crude protein (%)	77.2	77.3	76.0	78.4	0.84	<0.001	0.51	1.3
Ether extract (%)	81.5	80.4	79.0	82.9	0.09	<0.001	0.02	1.3
Crude fibre (%)	21.3	21.9	19.6	23.6	0.65	<0.01	0.47	4.4
Neutral detergent fibre (%)	30.7	31.6	30.7	31.6	0.43	0.38	0.92	3.7
Acid detergent fibre (%)	18.2	18.9	17.7	19.4	0.56	0.20	0.68	4.5
Gross energy (%)	65.3	65.6	64.3	66.6	0.60	<0.001	0.59	1.9
Digestible energy (DE) (MJ/kg)	10.8	10.9	10.6	11.1	–	–	–	–
Digestible protein (DP) (g/kg)	124	124	117	131	–	–	–	–
DP to DE ratio (g/MJ)	11.4	11.4	11.0	11.9	–	–	–	–

[1]Third week of restriction period.

M, diet with moderate digestible energy; H, diet with high digestible energy; RMSE: root mean square error.

Table 4: Slaughter traits and main characteristics of 24–h chilled carcasses (least squares means).

	Feed restriction (R)		Feeding plan (P)			P-value			
	ad libitum	Restricted	MM	MH	HH	R	P	R×P	RMSE
Rabbits (n)	98	101	67	68	64				
Slaughter weight (SW) (g)	2585	2564	2564	2579	2579	0.53	0.92	0.87	247
Transport losses (%)	2.0	2.1	2.0	2.1	2.0	0.47	0.67	0.22	0.9
Full gut incidence (% SW)	17.6	17.7	17.6	17.8	17.5	0.78	0.53	0.18	1.3
Cold carcass (CC) (g)	1591	1582	1581	1582	1596	0.69	0.84	0.58	163
Dressing out (% SW)	61.5	61.7	61.6	61.3	61.9	0.51	0.07	0.09	1.5
Reference carcass (RC) (g)	1328	1320	1326	1320	1325	0.77	0.98	0.54	142
Dissectible fat (% RC)	3.03	2.80	2.79	2.87	3.09	0.13	0.22	0.92	0.78
Muscle to bone ratio of hind leg	6.24	6.29	6.11	6.22	6.46	0.77	0.16	0.14	0.63

MM, diet with moderate digestible energy during 5 wk; MH, M diet for the first 3 wk and H diet for the last 2 wk. HH, diet with high digestible energy during 5 wk. RMSE: root mean square error.

Feed restriction did not affect transport losses, dressing out percentage and carcass traits (Table 4), whereas severe restriction rates, long restriction periods and short re-feeding phases may be effective on these traits (Tůmová *et al.,* 2006; Gidenne *et al.,* 2012).

In addition, we observed that EB composition at 69 d of age and EB gains between 34 d and 69 d of age were not affected by feed restriction (Tables 5 and 6). However, during the first period (34 to 55 d), EB gains of protein (193 *vs.* 180 g) and lipid (111 *vs.* 105 g) were higher ($P<0.001$), as well as for gross energy (9.1 MJ *vs.* 8.5 MJ), in L rabbits than in R ones (data not reported in table). In contrast, during the second period the previously restricted rabbits showed compensatory growth and higher ($P<0.05$) EB gains of protein (121 *vs.* 126 g) and lipid (91 *vs.* 97 g), as well as gross energy (6.8 *vs.* 7.1 MJ) (data not reported in table), which determined similar material and energy body balance in the two groups in the whole trial.

As for N balance, at the end of the restriction period (55 d of age), EB protein content was significantly lower ($P<0.05$) in rabbits submitted to feed restriction compared to rabbits fed *ad libitum* (Table 5). Thus, feed restriction decreased body N at 55 d ($P<0.001$), as well as total N ingestion (–3.2%; $P<0.05$), and daily N excretion (–3.7%; $P<0.05$) in

Table 5: Empty body (EB) composition (least squares means) measured by comparative slaughter[1].

	Feeding (R)		Feeding plan (P)			P-value			
	ad libitum	Restricted	MM	MH	HH	R	P	R×P	RMSE
Rabbits (n)	18	18	12	12	12				
EB composition at 55 d									
Water (g/kg)	679	686	683	682	683	0.31	0.99	0.81	19
Protein (g/kg)	192	189	190	191	191	0.05	0.94	0.06	5
Lipid (g/kg)	96	95	95	95	96	0.88	0.98	0.86	21
Ash (g/kg)	33	30	32	32	30	0.02	0.13	0.47	3
Gross energy[2] (MJ/kg)	8.52	8.35	8.36	8.45	8.51				
EB composition at 69 d									
Water (g/kg)	659	662	660	663	658	0.65	0.75	0.92	16
Protein (g/kg)	197	195	195	195	198	0.31	0.33	0.80	6
Lipid (g/kg)	112	113	113	111	113	0.86	0.94	0.96	19
Ash (g/kg)	32	30	32	31	31	0.11	0.53	0.75	3
Gross energy[2] (MJ/kg)	9.35	9.24	9.27	9.32	9.40				

[1]Empty body composition at initial slaughter (12 rabbits slaughtered at 34 d): water, 723 g/kg; protein, 176 g/kg; lipid, 69 g/kg; ash, 32 g/kg; energy, 7.09 MJ/kg.

[2]Gross energy content was measured on pooled empty bodies of slaughtered rabbits within each experimental treatment.

MM, diet with moderate digestible energy during 5 wk; MH, M diet for the first 3 wk and H diet for the last 2 wk. HH, diet with high digestible energy during 5 wk. RMSE, root mean square error.

Table 6: Empty body (EB) gain composition and nitrogen balance (least squares means) from 34 d to 69 d of age.

	Feeding (R)		Feeding plan (P)			*P*-value			
	ad libitum	Restricted	MM	MH	HH	R	P	R×P	RMSE
Rabbits (n)	116	119	79	80	76				
EB gain from 34 to 69 d (g)	1504	1489	1483	1516	1491	0.53	0.52	0.77	187
EB gain composition									
Water (g)	941	936	929	957	929	0.78	0.26	0.83	122
Protein (g)	314	306	305	311	314	0.11	0.29	0.47	37
Lipid (g)	202	203	203	201	204	0.81	0.65	0.19	22
Energy (MJ)	15.9	15.6	15.5	15.9	15.9	0.30	0.27	0.15	1.8
Body N at 34 d[1] (g)	22.6	22.4	22.4	22.4	22.6	0.61	0.79	0.85	2.5
Body N at 55 d[1] (g)	53.5	51.2	52.2	52.1	52.8	<0.001	0.68	0.42	5.2
Body N at slaughter[1] (g)	72.8	71.4	71.1	72.2	72.8	0.13	0.33	0.64	7.1
Total ingested N (g)	125	121	120	124	126	0.04	0.03	0.99	4.8
Total retained N (g)	50.2	49.0	48.7	49.8	50.2	0.11	0.29	0.47	6.0
Daily excreted N (g/d)	2.16	2.07	2.03[a]	2.12[ab]	2.17[b]	0.04	0.01	0.74	0.28

MM, diet with moderate digestible energy during 5 wk; MH, M diet for the first 3 wk and H diet for the last 2 wk. HH, diet with high digestible energy during 5 wk. RMSE: root mean square error.

[1]Data calculated on the basis of the body protein content of rabbits submitted to comparative slaughters.

[a,b]Means with different superscript letters are statistically different ($P<0.05$).

the whole trial (34-69 d) (Table 6). Similarly, other authors (Gidenne *et al.,* 2013a; Birolo *et al.,* 2016) found that both severe and mild feed restriction rates play a key role in reducing N excretion on rabbit farms due to the higher feed efficiency in comparison with *ad libitum* feeding.

Effect of feeding plans

The increase in dietary energy represents a well-known strategy to control feed intake, improve feed efficiency and reduce nitrogen excretion in growing rabbits when proper levels and ratios among starch and fibre fractions are provided (Maertens, 2010; Tazzoli *et al.,* 2015).

In fact, under our conditions, the use of H diet in comparison with M diet throughout the trial improved feed conversion (by 2.7%; $P<0.05$) thanks to the reduction ($P>0.05$) in feed intake, without differences in growth rate (Table 2). A significant improvement in feed conversion due to a moderate increase in dietary energy has been reported in rabbits fed *ad libitum* by different authors (Renouf and Offner, 2007; Montessuy *et al.,* 2009) and without effects on daily growth (Fernández Carmona *et al.,* 2000; Maertens, 2010). In contrast, when DE content increased from low to moderate or high values, other authors (Gidenne *et al.,* 2009b; Knudsen *et al.,* 2014; Read *et al.,* 2015) described improved daily weight gain of rabbits either fed *ad libitum* or submitted to feed restriction.

As expected, in our trial, the digestibility coefficients of most nutrients were higher for H diet than M diet (Table 3) due to the lower content in insoluble fibre fractions and the higher content in starch and high-quality protein. Accordingly, the DE and digestible protein (DP) contents increased in H diet (+0.5 MJ/kg and +14 g/kg, respectively) and the DP to DE ratio ranged from 11.0 g/MJ in M diet to 11.9 g/MJ in H diet. Knudsen *et al.* (2014) reported that feed restriction improved digestibility to a greater extent when rabbits were fed a high-energy diet compared to a low-energy diet, while in our trial no significant interaction between the feeding system and the DE content of diets was measured on nutrient digestibility. Differences in restriction rates as well as the variability of DE content among and within the studies may account for these different results.

Some authors also observed a positive relationship between digestive health risk and DE increase regardless of the feeding system (*ad libitum* or restricted) (Knudsen *et al.,* 2014). On the other hand, other authors (Bebin *et al.,* 2009; Montessuy *et al.,* 2009; Read *et al.,* 2015) did not observe significant effects of dietary energy content on rabbit health. In this case, differences among experimental results depended on the levels and ratios among the dietary fibre fractions, starch and protein (Gidenne, 2015; Tazzoli *et al.,* 2015). Although our trial did not aim to evaluate the effects of the feeding treatments on health and an antibiotic treatment was administered to limit the mortality due to ERE, the absence of differences in mortality among groups is worth mentioning.

As observed for growth performance, the feeding plan did not affect dressing percentage and carcass traits (Table 4), as large differences in the dietary DE content and DP to DE ratio are required to determine significant changes in carcass yield and slaughter traits (Xiccato, 1999; Dalle Zotte, 2002). In fact, in other studies, when DE content increased from low (about 9 MJ/kg) to moderate (about 10 MJ/kg) and high (about 11 MJ/kg) values, dressing out percentages improved (Renouf and Offner, 2007; Knudsen *et al.,* 2014), which mainly depended on the increased growth rate and final live weight of rabbits.

Finally, in our trial, the different feeding plans did not affect EB gain or composition either in the first or second period of growth (Tables 5 and 6). However, N intake and excretion were higher in rabbits submitted to the HH plan than in those fed the MM plan due to the higher DP to DE ratio of H diet compared to M diet, as also reported by Gidenne *et al.* (2013b) in rabbits fed diets with different DP to DE ratio (from 9.4 g/MJ until 13.6 g/MJ).

CONCLUSIONS

Growth rate, body balance and carcass traits were scarcely affected by a mild feed restriction during the post weaning period, but feed efficiency and environmental impact were improved in terms of reduced feed conversion and N excretion. Growth rate, slaughter traits or nitrogen retention did not change with continuous or phase feeding plans based on high and/or moderate energy diets. Finally, nitrogen excretion was confirmed to depend mainly on dietary nitrogen content.

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