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FEEDING AND MEAT QUALITY IN RABBITS: A REVIEW [1]

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ABSTRACT: The principal objectives of rabbit feeding strategies are to limit digestive disorders, shorten rearing time and increase dressing percentage. Besides, new attention is placed on the carcass composition in terms of primal joint cut, fat and lean proportions, and on the technological and sensory characteristics of the meat, due to the increasing demand for processed meat. The possibility of modifying carcass and meat quality has been demonstrated to be very limited when rabbits are fed a balanced diet *ad libitum*. Only extreme situations like severe restriction and lack or large excess in a specific nutrient are able to influence slaughter traits and meat characteristics. However, growth performance and health conditions may be also compromised. The manipulation of the development rate of the different body tissues seems to be possible through adequate feeding programs based on different protein levels in relation to dietary energy, but more studies are required to clarify the variations of protein and amino acid requirements throughout the entire growing period. From the literature, it clearly appears that fat addition to the diet, both as inclusion level and source, significantly affects carcass fatness and meat fatty acid composition. The consequences are evident in the organoleptic appreciation of rabbit meat and also in its technological characteristics. Therefore further studies are required in order to investigate the biochemical processes that determine post-mortem transformation of muscles into meat and the evolution during storage.

RESUME : Alimentation et qualité de la viande de lapin : une revue. Les principaux objectifs des stratégies d'alimentation du lapin sont de limiter les problèmes digestifs, de raccourcir la durée d'engraissement et d'améliorer le rendement à l'abattage. En outre, depuis quelque temps, une attention particulière est portée sur la composition de la carasse en termes de proportions de morceaux nobles, de gras et de maigres ainsi que de qualités technologiques et sensorielles de la viande, en raison d'une demande croissante pour les produits transformés. Il a été démontré que les possibilités de modification des caractéristiques de la carcasse et de la viande sont très limitées lorsque les lapins sont nourris *ad libitum* avec un aliment équilibré. Seuls une restriction alimentaire sévère, un excès ou une carence marqués en un nutriment spécifique sont susceptibles de modifier les performances à l'abattage et les caractéristiques de la viande. Dans ce cas, les performances de croissance et sanitaires sont également altérées. Le contrôle du développement relatif des différents tissus corporels semble possible grâce à un programme alimentaire basé le taux de protéines en relation avec la concentration énergétique de l'aliment, mais des études complémentaires sont encore nécessaires pour bien préciser les variations des niveaux de protéines et d'acides aminés souhaitables tout au long de la croissance. L'analyse de la littérature montre clairement que l'addition de matières grasses dans l'aliment, quel que soit le taux d'incorporation ou la provenance, affecte significativement l'adiposité de la carcasse et la composition en acides gras de la viande. Les conséquences sont évidentes sur l'appréciation organoleptique et les caractéristiques technologiques de la viande des lapins. C'est pourquoi l'étude des processus biochimiques intervenant dans la transformation *post mortem* du muscle en viande et son évolution pendant le stockage doit être poursuivie.

INTRODUCTION

The control and improvement of carcass and meat quality is assuming greater and greater importance in rabbit production. Indeed, the increasing integration of the different sectors of the entire rabbit "filière" (production, slaughter, transformation and marketing) makes the quality of the carcass more important and requires that all the production factors be considered as essential parts of the process and therefore carefully controlled.

Although feeding has always been considered as an important variation factor in meat quality (OUHAYOUN *et al.*, 1986; OUHAYOUN, 1989), only minor changes in carcass traits and meat composition have been experimentally recorded until now. One of the principal cause of the scarce effect of feeding on rabbit quality is related to the limits imposed by rabbit digestive physiology, narrower than those of other species (e.g. swine, poultry), that prevents large variations in the composition of the diet.

Another cause of the lack of repeatable effects of feeding on rabbit quality is linked to the different meaning that "quality" assumes (PARIGI BINI, 1992). Rabbit carcass quality can be defined by several traits but the most important for the breeder is the slaughter weight, which is conditioned by local market demand and often represents an important obstacle in the attempt to modify carcass characteristics. Dressing out percentage is the principal variable for slaughterers and vendors when carcasses are sold entire or in half carcasses, while the proportion of the different tissues (fat and muscles) and commercial cuts are particularly important for the slaughterers when the carcasses are cut (in loins, legs) or sold as processed meat. Rabbit meat quality can also be described by its chemical, physical and sensorial traits, which are the most critical characteristics for the final consumer, although rarely appreciated and taken into economic consideration by breeders, slaughterers and vendors.

Other limits to the achievement of definitive and universally valid results in the improvement of rabbit meat quality are the wide variations in genotype (pure

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Table 1 : Empty body gain (EBG) composition and body retained energy as influenced by DE intake (all data are in kJ or g/day/kg $LW^{0.75}$) (PARIGI BINI and XICCATO, 1986, 1998)

DE intake	EBG	Empty body gain composition				Retained
(kJ)	(g)	Water (g)	Protein (g)	Fat (g)	Ash (g)	energy (kJ)
0	-12.6	-6.5	-2.4	-2.8	-0.9	-155
273	0.0	1.8	0.2	-1.9	-0.1	-62
425	6.5	5.8	1.5	-1.0	0.2	0
800	21.0	13.5	4.5	2.3	0.7	186
1000	27.8	16.4	5.9	4.7	0.8	303

breeds and commercial hybrids), commercial slaughter weight (from 2 to 3 kg) as required by national and regional markets, and form of consumption (entire or half carcasses, retail cuts or processed products).

THE LIMITS OF RABBIT DIGESTIVE PHYSIOLOGY

As mentioned above, the possibility of widely changing the composition of rabbit diets is limited by the need for various nutrients and the balance among them. Digestive disorders easily appear when crude fibre is lower than 12% in fattening rabbits or 14-15% in weaning and post-weaning rabbits (LEBAS, 1989; GIDENNE, 1996). At the same time, starch exceeding 15% in weaning diets and 25% in fattening diets can induce a negative modification of gut micro flora and provoke diarrhoea and even death. Dietary protein utilisation is influenced not only by its digestibility and the correct amount of essential amino acids, but also by the ratio between protein and energy, usually expressed as the ratio between digestible protein and digestible energy concentrations (DP/DE). The values usually recommended for fattening rabbits range from 10 to 11g DP/MJ DE.

In other species, the increase of energy concentration and the reduction of DP/DE provoke a clear modification of tissue development, with a decrease in muscle growth and an acceleration in fat deposition (WILSON, 1981; LAWRIE, 1991). On the contrary, an increase in protein concentration promotes muscle growth and slows down fattening. These feeding modifications either accelerate or delay animal growth finishing and offer a valid mean for the production of ready-to-market carcasses of different age and weight.

In rabbits, even if the same growth model has been demonstrated by FRAGA *et al.* (1983), any major deviation from the correct protein to energy ratio may cause digestive disorders and increase mortality before providing the desired results in the modification of relative tissue growth and consequent carcass and meat quality.

DIETARY ENERGY CONCENTRATION AND FEED RESTRICTION

The control of appetite is very efficient in rabbits and any increase or decrease of dietary energy concentration determines an inverse modification in feed ingestion. Appetite regulation in rabbits is mostly controlled by a chemiostatic mechanism, therefore the total quantity of energy ingested daily tends to be constant. Voluntary intake is proportional to metabolic live weight ($LW^{0.75}$) and is about 0.9 to 1.0 MJ DE/day/kg $LW^{0.75}$. The chemiostatic regulation occurs only with a DE concentration of the diet higher than 9 to 9.5 MJ/kg (LEBAS *et al.*, 1984; PARTRIDGE, 1986; CHEEKE, 1987), below which level a physical-type regulation linked to the filling of the gut by the dietary material takes place. However, the energy intake can be modified either by imposing feed restrictions or by adding fat to the diet.

Growing and finishing rabbits are usually fed to appetite to avoid growth performance reduction (MAERTENS, 1992). However, feed is often rationed for short periods after weaning in order to reduce the risk of over-ingestion and digestive disorders, but its effectiveness is controversial. In fact, a feed restriction during the first weeks after weaning could increase the risk of diarrhoea, because a lower feed intake leads to increased digesta retention time and consequently higher caecal pH and ammonia-N concentrations (MAERTENS, 1992, GIDENNE, 1996).

In all the experiments to study the modification of body weight gain and tissue proportion, feeding restriction causes lower daily gain, fat deposition, and body energy retention.

PARIGI BINI and XICCATO (1986, 1998) described a growth model depending on DE intake (DEI). During starvation, the rabbit looses 12.6 g/day of empty body weight per kg metabolic weight ($LW^{0.75}$) while maintaining its weight with a DE intake of 273 kJ/day/kg $LW^{0.75}$(Table 1). At this intake level, a loss of energy is observed due to a loss of fat. When DE intake is equal to the maintenance requirement (425 kJ/day/kg $LW^{0.75}$), the energy balance is reached as a consequence of a gain of energy as protein and an equivalent loss of energy as fat. When DEI reaches the maximum value (about 1000 kJ/day/kg $LW^{0.75}$), which corresponds to the voluntary intake, retained energy also reaches the maximum level. With increasing DEI, protein is deposited at a slower rate than fat (Figure 1).

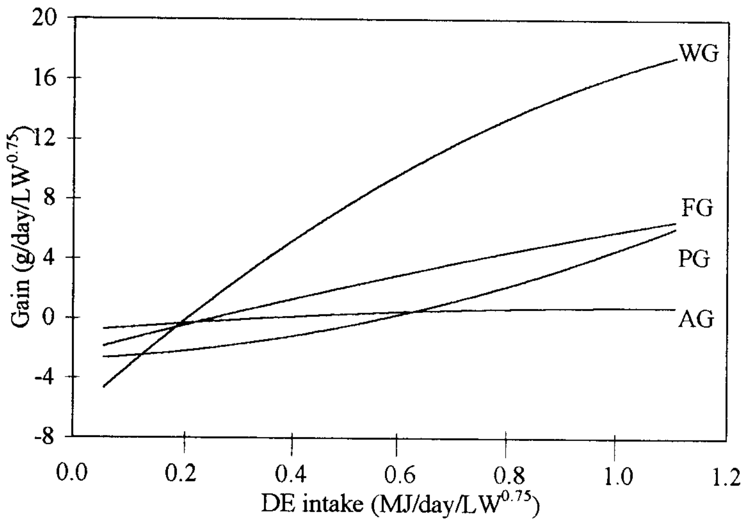

Figure 1 : Influence of DE intake on empty body gain composition (WG: water gain; FG: fat gain; PG: protein gain; AG: ash gain) (from PARIGI BINI and XICCATO, 1986, 1998)

These growth models can be used to calculate the daily gain composition throughout the entire growing period (e.g. from 0.7 to 2.5 kg LW). Table 2 gives the estimation of daily growth and final body composition in rabbits fed at different restriction levels (80, 85, 90 and 95% of voluntary intake). As an example, a feed restriction up to 90% of the voluntary intake throughout the entire growing period decreases daily gain from 45.3 to 39.9 g/day, delays slaughter by 5 days, and reduces body fat concentration from 13.8 to 11.7% and energy concentration from 9.81 to 9.08 MJ/kg without considerable changes in body protein and ash.

The effect of feed restriction on quantitative and qualitative performance has been studied for a long time to improve feed efficiency, and standardise the growth curve in

Table 2 : Changes in daily gain and body composition at 2500 g live weight according to feeding level (recalculated from PARIGI BINI and XICCATO, 1986, 1998)

Feeding level (%)	DEI (kJ/day/kg LW$^{0.75}$)	DEI (kJ/day)	Growing period (days)	LW gain (g/day)	E BG (g/day)	Final empty body composition[1]				
						Water (%)	Protein (%)	Fat (%)	Ash (%)	Energy (MJ/kg)
80	800	1136	52.6	34.2	29.8	66.2	21.0	9.4	3.4	8.29
85	850	1207	48.5	37.1	32.3	65.2	20.9	10.6	3.3	8.70
90	900	1278	45.1	39.9	34.7	64.2	20.9	11.7	3.3	9.08
95	950	1349	42.2	42.6	37.1	63.2	20.8	12.7	3.2	9.42
100	1000	1420	39.8	45.3	39.5	62.3	20.8	13.8	3.1	9.81

[1]Calculation is based on an initial LW of 700 g and the following initial body composition: EBW = 0.87 LW; water 71.0%; protein 19.7%; fat 5.8%; ash 3.5%; energy 6.70 MJ/kg.

Table 3 : Effect of feed restriction on growth performance and carcass and body composition.

Reference	Restriction Level (%)	Slaughter age (days)	Slaughter weight (kg)	Weight gain (g/d)	Dressing percentage (%)	Perirenal fat (% LW)	Final empty body composition			
							Water (%)	Protein (%)	Fat (%)	Ash (%)
PARIGI BINI *et al.* (1974)	90	86	2.4	25.7			69.2	21.8	6.3	3.7
	75	86	2.1	20.1			71.0	21.6	4.0	3.3
	65	86	1.6	9.2			72.5	21.9	2.0	3.6
SCHLOLAUT *et al.* (1978)	100	73	3.2		59.1	3.2	60.9	18.6	16.6	3.6
	80	92	3.2		56.3	2.2	65.8	19.4	9.8	3.9
	60	133	3.2		55.5	1.4	67.4	20.0	5.5	4.6
OUHAYOUN *et al.* (1986c)	80	105	2.7		61.8	5.2				
	54	140	2.7		60.7	1.6				
CAVANI *et al.* (1991)	100	81	2.64	30.5	60.1	1.2				
	90	81	2.49	28.1	59.7	0.9				

animals with different voluntary feed intake (OUHAYOUN *et al.*, 1986c; OUHAYOUN, 1989; CAVANI *et al.*, 1991). Table 3 summarises the results of some studies where feeding level varied from appetite to 54% of appetite. They confirm the reduction of carcass fatness and also demonstrate a decrease in dressing percentage.

More recently, other studies have been conducted to avoid over-ingestion and modify carcass and meat quality. PERRIER and OUHAYOUN (1996) compared three rationing methods which were identical with respect to the overall level of restriction (80%) but differed in the feeding plan: restriction at 80% of appetite level throughout the entire growing period from 35 to 77 days of age; restriction at 70% level from 35 to 56 days followed by restriction at 90% level from 56 days thereafter; and restriction at 90% level from 35 to 56 days followed by restriction at 70% level. The results, summarised in Table 4, demonstrate that daily gain and feed efficiency were higher in the 70-90 treatment. The most liberal feed intake during the second period of growth reduced dressing percentage, did not modify the incidence of fat and stimulated muscle to bone ratio in comparison with the 90-70 treatment. The ultimate pH was also affected by the rationing mode, indicating possible changes in technological and sensorial meat traits.

Other studies have been conducted to evaluate the effect of different methods of feed restriction, by limiting the access to feed either for some hours a day or some hours a week (CAVANI *et al.*, 1991; CASTELLÓ and GURRI, 1992; JÉRÔME *et al.*, 1998). As observed in previous studies, feed rationing played a significant role in modifying body gain and carcass traits, whereas the limited access to feed for a few hours a day or the distribution of a feed quantity equivalent to the voluntary intake but divided into two or more fractions a day did not produce significant effects (CAVANI *et al.*, 1991). However, the limitation of access to feed to only 16 h per day (from 8 p.m. to 8 a.m.) reduced carcass fattening without significantly decreasing daily growth and dressing percentage (JÉRÔME *et al.*, 1998).

Table 4 : Effect of different rationing plans on growth performance and carcass quality (from PERRIER and OUHAYOUN, 1996).

	Feeding plan			Prob.
	80-80	**70-90**	**90-70**	
Live weight at slaughter (LW) (g)	2302[b]	2402[c]	2217[a]	**
Daily gain (g/d)	29.9[b]	32.3[c]	27.9[a]	**
Feed intake (g/d)	123	124	121	
Conversion index	4.13[b]	3.87[a]	4.40[c]	**
Chilled carcass weight (g)	1389[b]	1416[b]	1334[a]	**
Hindleg muscle weight (g)	165[b]	166[b]	157[a]	**
Perirenal + scapular fat weight (g)	31.3[ab]	34.5[b]	28.3[a]	*
Chilled dressing percentage (%)	60.3[b]	59.0[a]	60.1[b]	**
Renal+scapular fat (% ref. carcass)	2.69	2.96	2.53	
Hindleg muscle/bone ratio	6.28[b]	6.32[b]	5.98[a]	*
Average ultimate pH	5.77[b]	5.73[a]	5.77[b]	*

*: $P<0.05$; **: $P<0.01$.

PERRIER (1998) applied two feeding restriction levels (70% or 50% of *ad libitum*) during the early growing period (from 35 to 56 days of age), followed by *ad libitum* feeding in the finishing period to investigate the effect of realimentation. Despite the presence of compensatory growth in the final period, an early feed restriction provoked lower final weight and dressing percentage and decreased fat contents by 12 to 25% compared to the *ad libitum* treatment (Table 5).

Table 5 : Effect of the feed restriction level during the post-weaning period on the carcasses of rabbits slaughtered at 77 days of age
(from PERRIER, 1998)

	Restriction level (%)			Prob.
	100	**70**	**50**	
Slaughter weight (g)	3059[a]	2877[b]	2772[c]	***
Daily gain (g/d)	45.8[a]	41.6[b]	39.0[c]	***
Feed conversion	3.74[a]	3.66[a]	3.56[b]	**
Dressing percentage (%)	59.13[a]	58.83[a]	57.38[b]	***
Liver (% commercial carcass)	5.72[b]	5.85[b]	6.74[a]	***
Anterior part (% reference carcass, RC)	28.75	28.43	28.92	
Intermediate part, (% RC)	30.81	31.11	30.89	
Posterior part (% RC)	36.30[b]	36.55[ab]	36.96[a]	*
Perirenal + scapular fat (% RC)	4.17[a]	3.61[b]	3.15[c]	***
Hind leg muscle/bone ratio	6.26[a]	6.28[a]	5.99[b]	***

*: $P<0.05$; **: $P<0.01$;***: $P<0.001$.

It is clear that while even

slight feeding restriction provokes a sharp decrease in daily growth, a more severe restriction is required to obtain substantial changes in body composition. On the contrary, any feeding or rearing system that promotes an increase in growth rate also stimulates the development of late-stage tissues (especially fat) more than precocious tissues (OUHAYOUN *et al.*, 1986b; PERRIER and OUHAYOUN, 1996).

The general opinion on feed restriction practice and/or realimentation is that unavoidable detrimental effects on growth performance are not counterbalanced by a real improvement in feed conversion and carcass quality. Moreover, feed rationing is difficult to apply in collective cage rearing systems because it may increase heterogeneity in weight and body composition. However, for some particular types of production (e.g. "labelled" rabbits), feed restriction might produce leaner carcasses by reducing growth rate, this way being more appreciated by the consumer, who will be willing to pay a higher price to compensate the breeder for the lower weight produced (JÉRÔME *et al.*, 1998). On the other hand, an excessive decrease in the intramuscular fat consequent of feed restriction could be detrimental for juiciness and flavour of the meat, even though the relationship between intramuscular fat and sensory traits of meat is not yet proved (GONDRET and BONNEAU, 1998).

FEEDING PLANS

Feeding plans or phase feeding are developed to cover different nutritive requirements at different ages. During post-weaning, rabbits are usually fed moderate energy diets with high DP/DE to avoid digestive problems and stimulate muscular growth. During fattening, the diet is more concentrated in energy and less in protein and permits the finishing of the carcass through the deposition of an adequate quantity of fat. Several studies have been conducted to evaluate the effect of different feeding plans on *infra vitam* performance, but few have investigated their effect on *post-mortem* characteristics.

The influence of the feeding plan on carcass and meat properties is moderate. In particular, the energy concentration of feed given during the post-weaning period did not significantly affect dressing percentage when the animals were fed a high-energy diet during fattening (LEBAS *et al.*, 1982; XICCATO *et al.*, 1993; XICCATO *et al.*, 1998). When feeding plans based on high energy diets were used also during the post-weaning period, carcass adiposity and intramuscular fat tended to increase. DALLE ZOTTE *et al.* (1996) found lower final pH and higher aldolase activity in the *longissimus dorsi* muscle of rabbits fed a high-energy diet during the post-weaning period, whereas meat chemical composition and lightness were not affected.

DIETARY PROTEIN CONCENTRATION AND PROTEIN TO ENERGY RATIO

Dietary protein can be changed either by modifying protein concentration without changing the energy concentration or by varying energy accordingly to protein. In the former case, the DP/DE value changes and protein ingestion changes as well; in the latter, both protein and energy intake remain constant because of appetite regulation. Therefore, the only parameter useful for the appreciation of dietary protein is the DP/DE value.

The variation of dietary DP/DE may affect body composition when the total protein ingestion does not cover the daily protein requirement. With low DP/DE, protein intake is lower than the optimal daily quantity of 19-20 g CP (CHEEKE, 1987) or 12-14 g DP (DE BLAS *et al.*, 1985; PARIGI BINI and XICCATO, 1986). This impairs growth performance and reduces consequently fat deposition (CHIERICATO *et al.*, 1983; LEBAS and OUHAYOUN, 1987) or favours high fat deposition because muscular protein accretion is sub-optimal (LANARI *et al.*, 1972; OUHAYOUN and CHERIET, 1983; FRAGA *et al.*, 1983; OUHAYOUN, 1989). When DP/DE is higher than the optimal value of 10.5 to 11 g/MJ (LEBAS, 1989) and therefore the daily protein requirement is fully covered, muscular protein synthesis reaches its maximum potential and the protein in excess is used as an energy source. This available energy tends to rebalance the protein to energy ratio and maintain the body gain composition constant. For this reason, the effect of increasing DP/DE over the recommended values generally has no effect on *infra vitam* and *post-mortem* traits (RAIMONDI *et al.*, 1974a; XICCATO *et al.*, 1993) or is limited to a slight reduction of fat deposition when DP/DE is very high (>12 g/MJ) (MAERTENS *et al.*, 1988). However, DP/DE higher than 14 g/MJ significantly reduces perirenal fat weight, but negatively affects daily gain, feed conversion, fleshiness, and mortality (KJÆR and JENSEN, 1997).

Increasing dietary protein supply stimulates muscular growth and increases muscular protein concentration, particularly the sarco plasmic fraction (OUHAYOUN and DELMAS, 1983). A higher proportion of αW muscle fibres and increased glycolitic activity has been also observed.

MAERTENS *et al.* (1997) observed substantial modification in the *infra-vitam* performance and body composition of rabbits fed six isoenergy diets (DE = 10.4 MJ/kg) with increasing crude protein concentration (from 13.8 to 17.0%) and DP/DE (from 8.5 to 12.3 g/MJ, recalculated values). During the entire growing

Table 6 : Effect of dietary protein level on carcass traits and EB composition (MAERTENS *et al.*, 1997)

Dietary protein concentration (%) DP/DE (g/MJ)	13.8 8.5	14.4 9.2	15.1 9.8	15.7 10.5	16.4 11.8	17.0 12.3	Prob.
Live body weight (g)	2774[a]	2842[ab]	2844[ab]	2961[c]	2932[bc]	2997[c]	***
Chilled carcass (g)	1693	1681	1675	1678	1699	1680	
Separable fat (g)	86.2	91.3	91.3	96.0	97.2	94.1	
Dressing percentage (%)	58.5	58.1	57.9	58.0	58.7	58.1	
Empty body composition:							
Water (g/kg)	650[a]	658[ab]	660[b]	655[ab]	656[ab]	670[c]	*
N x 6.25 (g/kg DM)	511[a]	534[b]	539[b]	539[ab]	540[b]	576[c]	**
Fat (g/kg DM)	338[a]	326[a]	316[a]	315[a]	318[a]	284[b]	*
Ash (g/kg DM)	111	106	111	111	102	108	

*: P<0.05; **: P<0.01; ***: P<0.001.

period, average daily growth increased as dietary protein increased until 15.7% (corresponding to a DP/DE equal to 10.5 g/MJ), and then remained unchanged (Table 6). Body composition was characterised by significantly higher fat and lower protein (N x 6.25) and water concentrations in rabbits fed the lowest dietary protein level (DP/DE <9.5 g/MJ) and by lower fat and higher protein and water proportions in rabbits fed the highest protein level (DP/DE >12 g/MJ). Intermediate and similar body compositions were observed in the rabbits fed the diets characterised by DP/DE ranged 9.5 to 12 g/MJ. Dressing percentage and separable fat weight did not vary at any protein level. These data confirm that weight gain is limited by a daily DP intake below the minimum level but body composition does not change significantly even if protein intake varies in a wide range among this quantity. In conclusion, only extreme variations in DP/DE are able to modify body composition.

The variation of protein requirements during growth makes the effect of dietary protein concentration extremely difficult to evaluate. Protein requirements decrease both in total quantity and in specific amino acid supply as growth proceeds, but few studies have been conducted on protein and amino acids requirement at specific physiological stages (PARIGI BINI *et al.*, 1988; MAERTENS *et al.*, 1997). Besides, little information is available on the effect of changes in the dietary protein on carcass and meat quality from the weaning to fattening periods.

Low protein diets during post-weaning result in low dressing out percentage as a consequence of impaired growth performance in the first period of fattening (OUHAYOUN, 1989). The early administration of low-protein diets slows down rabbit muscle development in the first phases of fattening and tends to induce a compensative growth in last period of fattening, in this way postponing the beginning of fat deposition (LEBAS and OUHAYOUN, 1987). According to these results and those of FRAGA *et al.* (1983), the fat content of meat tend to increase when the DP/DE ratio is increased during the early stage. DALLE ZOTTE *et al.* (1997) also observed a higher fat deposition in the carcass of rabbits fed a diet with high DP/DE ratio for a longer time during post-weaning. On the contrary, diets with different DP/DE ratios given during the fattening period did not modify carcass and meat composition (XICCATO *et al.*, 1993).

AMINO ACID CONCENTRATION

Together with an adequate PD/ED, compound feeds for animals must guarantee a balanced supply of all essential amino acids. Methionine, lysine, and threonine are the most limiting dietary amino acids in rabbits. The effects of a deficiency of these amino acids are more evident in growth performance than in carcass traits. In fact, carcass dressing percentage and meat composition are influenced mostly as a consequence of the decrease in daily growth and depression in feed intake. No effect has been yet demonstrated in rabbits when the variation of amino acid supply do not modify growth rate.

The sulphur amino acids requirements in rabbits has been widely investigated (COLIN, 1975; SPREADBURY, 1978; TABOADA *et al.*, 1996), and feed supplementation with methionine generally improves growth performance (PARIGI BINI *et al.*, 1988; BERCHICHE and LEBAS, 1994; BERCHICHE *et al.*, 1995; TABOADA *et al.*, 1996). Higher dressing percentage, higher incidence of primal joints (fore and hind legs, loin and kidneys) (TABOADA *et al.*, 1996) and increased meat to bone ratio (BERCHICHE *et al.*, 1995) are also observed. However, when dietary methionine exceeds widely the recommended values, the carcass dressing percentage and fat deposition of rabbits are lowered (SCHOULAUT and LANGE, 1973).

According to LEBAS (1989), diets for growing rabbits should contain more than 0.64% of lysine (as-fed basis). The administration of increasing levels of lysine (until 0.76%) results in higher average daily gain and feed intake, while only slight improvement is produced by further addition (COLIN, 1975). PARIGI BINI *et al.* (1988) observed a positive effect of lysine supplementation (from 0.66 to 0.75%) on growth performances only in the first two weeks of fattening, confirming the reduction of the lysine requirement as age increases. Carcass dressing percentage increases as a consequence of lysine supplementation, but this improvement is associated to the positive influence on the growth rate (TABOADA *et al.*, 1994).

The effects of threonine addition to rabbit diets have not been fully investigated. DE BLAS *et al.* (1998) compared a basal diet containing 0.54% of threonine with four diets with increased levels of threonine (from 0.58% to 0.72%): the best growth performance were achieved at 0.58-0.63% of threonine, while higher or lower inclusion rates lead to worse results. Among carcass traits, only perirenal fat was significantly affected, and its incidence on the carcass increased until 0.63% of threonine and sharply decreased thereafter.

STARCH CONTENT AND QUALITY

Starch is considered as an important nutrient to be monitored. Indeed, it is the main dietary energy source in rabbit feeds and greatly affects the microbiological and biochemical activity of the gut (GIDENNE, 1996). As regards its influence on carcass and meat quality, it is very difficult to separate the effect of starch level from that of other dietary components, fibre, in particular. In fact, when starch concentration increases, crude fibre and fibre fraction concentration usually decrease. Therefore, most works have studied the effect of increasing levels of starch with concurrent decreasing levels of fibre (FRAGA *et al.*, 1983; DE BLAS *et al.*, 1986; PARTRIDGE *et al.*, 1989; GARCIA *et al.*, 1993).

Dietary starch concentration *per se* does not seem to affect rabbit body composition and meat quality, apart from its role in increasing diet energy concentration. PARIGI BINI *et al.* (1990) demonstrated that the increase of starch level from 15.4% to 22.9% with similar protein and fibre concentration did not affect growth performance, dressing percentage or empty body composition (Table 7), while it reduced feed intake and improved feed efficiency as the consequence of the increased DE concentration.

Increasing levels of starch from 18% to 28% DM in isoprotein and isofibre diets did not affect dressing percentage but significantly decreased water content and increased the protein content of the hind leg muscles; the source of the starch (maize or wheat) had no effect on carcass and meat quality (NIZZA *et al.*, 1995).

Table 7 : Effect of dietary starch on growth performance and body characteristics of growing rabbits slaughtered at 75 d of age (PARIGI BINI *et al.*, 1990).

Diets Starch (%)	Low starch 15.4	High starch 22.9
Slaughter weight (g)	2496	2452
Chilled dressing percentage (%)	61.9	61.5
Empty body composition:		
Water (%)	66.4	66.2
Protein (%)	20.6	21.3
Fat (%)	9.7	9.3
Ash (%)	3.2	3.2
Energy (MJ/kg)	8.40	8.38

FIBRE AND FIBRE FRACTION CONCENTRATION

Fibre concentration is a very important variable in rabbit diets due to its relationship with energy content and DP/DE. There is no evidence that crude fibre and fibre fractions play a specific effect on carcass and meat quality apart from their role in the modification of energy concentration. OUHAYOUN *et al.* (1986b) and OUHAYOUN (1989) reviewed several studies on this subject and observed that if growth rate is not impaired by fibre increase, dressing percentage is not modified. On the contrary, when high-fibre and low-energy diets provoke a decrease in voluntary DE intake, tissue growth and slaughter results are consistent with those observed with feeding restriction. When dietary fibre is over the recommended range (14 to 17%), dressing percentage is reduced as a consequence of sub-optimal growth performance (ABOUL-ELA *et al.*, 1996).

PARIGI BINI *et al.* (1994) compared three diets with rising crude fibre content (13.8, 16.3, 19.8%) and falling DE concentration (10.2, 9.3, 8.6 MJ/kg). No significant differences in dressing percentage, fattening, or muscle to bone ratio were observed as a result of diet composition. However, the higher the dietary fibre content was, the leaner and the richer in water the hind leg meat proved to be.

The increase of dietary fibre and the contemporary decrease in starch obtained by substituting 15 to 50% of the barley in the diet with the same proportion of sugar beet pulp lead to a significant increase in both stomach and cecal content, and therefore a reduction in dressing percentage (GARCIA *et al.*, 1992b; COBOS *et al.*, 1995). At the same time, body composition was modified with lower fat and higher water content (GARCIA *et al.*, 1992a) but fatty acid composition of meat remained unchanged (COBOS *et al.*, 1995). Unlike beet pulp, when starch sources were replaced with "traditional" fibre sources (i.e. alfalfa meal, grass hay, wheat straw) richer in cellulose and lignin, no significant variations in carcass traits were measured (PARTRIDGE *et al.*, 1989).

Decreasing levels of fibre and correspondingly increasing levels of starch produce higher cecum content in rabbits (DEHALLE, 1981; DE BLAS *et al.*, 1986), a sign of low passage rate and cecum constipation, whereas higher stomach contents can be found in rabbits fed high-fibre diets (DE BLAS, 1986; PARIGI BINI *et al.*, 1994), due to the presence of abundant soft faeces. These variations could account for some modification in dressing percentage.

FAT CONTENT AND FAT ADDITION

Despite the chemiostatic control of appetite, the addition of fat to diets results in higher DE intake accompanied by only a moderate reduction of feed intake: this improves rabbit daily gain and feed efficiency (PARIGI BINI *et al.*, 1974; BEYNEN, 1988; CASTELLINI and BATTAGLINI, 1992; FERNÁNDEZ *et al.*, 1994). Fat addition at moderate levels (2-6%) may also improve the digestive utilisation of the entire diet or single nutrients (SANTOMÁ *et al.*, 1987; FERNÁNDEZ *et al.*, 1994; XICCATO *et al.*, 1998). Higher levels (>9%) of fat to diets may lead to impaired rabbit performance (RAIMONDI *et al.*, 1973).

At present, the main reason for the addition of fat lies in its effect on the quality of carcass and meat. Indeed, the current trend is to breed heavier strains destined primarily for the production of commercial cuts; their characteristics of rapid growth and low precocity may cause low intramuscular lipid levels. The addition of fat to diets could overcome this problem by stimulating fat deposition in carcass and meat.

The effects of fat addition on carcass traits have been under investigation for a long time. On the whole, the principal effect of fat addition is the stimulation of carcass fat deposition in proportion to the fat inclusion rate (FERNÁNDEZ and FRAGA, 1996). An increase in carcass fatness was also observed as a residual effect of an added-fat diet fed only during the post-weaning period (until 45-55 d of age) (DALLE ZOTTE *et al.*, 1997; XICCATO *et al.*, 1998).

Low or moderate fat inclusion rates (2 to 6%) increase dressing percentage (PARIGI BINI, 1968; RAIMONDI *et al.*, 1974a; CASTELLINI and BATTAGLINI, 1992). The effects of higher inclusion rate are controversial, either impairing growth performance and slaughter results (LANARI *et al.*, 1972; RAIMONDI *et al.*, 1974a) or increasing dressing percentage (PLA and CERVERA, 1997).

Fat addition may also affect other carcass traits, by reducing liver incidence (FERNÁNDEZ and FRAGA, 1996), modifying biometric measurements, increasing lumbar circumference, or reducing the carcass length to circumference ratio (FERNÁNDEZ and FRAGA, 1996, PLA and CERVERA, 1997).

The main carcass traits are not influenced by the sources of added fat (FERNÁNDEZ and FRAGA, 1996, PLA and CERVERA, 1997) while rabbit meat quality is largely affected by the incorporation of animal or vegetable fats in the compound feed. This is not surprising, when considering that the main chemical characteristics of rabbit meat are always related to the total amount and composition of lipids. Rabbit meat is, in fact, appreciated for its low content of total fat and cholesterol and high proportion of polyunsaturated fatty acids (PUFA) and phospholipids (OUHAYOUN and LEBAS, 1987; LUKEFAHR *et al.*, 1989; CAMBERO *et al.*, 1991; PARIGI BINI *et al.*, 1992), which make rabbit meat a safe food for humans. The lipid composition of rabbit meat may have an incidence on flavour and juiciness (OUHAYOUN *et al.*, 1987; OLIVER *et al.*, 1997, GONDRET, 1998), and technological characteristics (BERNARDINI *et al.*, 1996; DAL BOSCO *et al.*, 1998).

High-fat diets increased fat content and decreased water content of empty body (LANARI *et al.*, 1972; COBOS *et al.*, 1993; FERNÁNDEZ and FRAGA, 1996). According to PLA and CERVERA (1997), the fat content of hind leg meat increased with fat addition (both vegetable and animal source) together with the contemporary reduction of water and protein. In some studies, however, the chemical composition of the *longissimus dorsi* muscle was not affected by feeding plans and diets at different levels of fat addition (RAIMONDI *et al.*, 1975; CASTELLINI and BATTAGLINI, 1992).

There is no doubt in regard to the influence of fat addition on the fatty acid (FA) composition of meat and separable lipids. The FA proportion changes not only as a function of the quantity of the fat added but especially as a result of the dietary FA composition. In fact, the short and medium-chain FA are mainly catabolized as energy sources, while the long-chain FA are more likely to be deposited directly in the adipose tissue (GONDRET, 1998; XICCATO, 1998). In this regard, fat source may play a significant role in modifying the lipogenic enzyme activity (GONDRET *et al.*, 1998).

As a result, the addition to the diet of a feedstuff rich in polyunsaturated FA (PUFA), such as sunflower or soybean oil, increased not only the weight of perirenal fat but also its PUFA proportion (OLIVER *et al.*, 1997) (Figure 2). Some erucic acid was also found in the

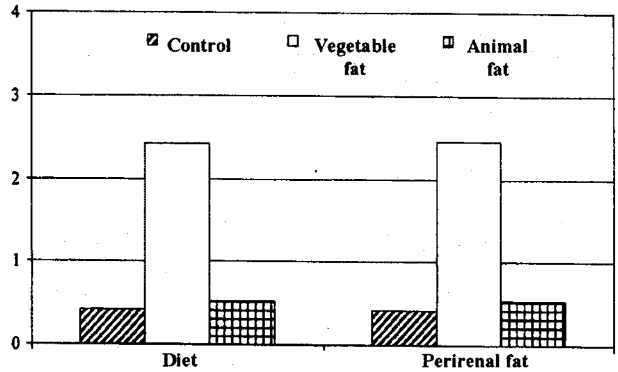

Figure 2 : Effect of dietary polyunsaturated to saturated fatty acids ratio on fatty acid composition of perirenal fat of rabbits fed diets without fat (Control) or including vegetable and animal fats (OLIVER *et al.*, 1997)

Table 8 : Effect of different sources of fat on the texture and flavour of rabbit loin (OLIVER *et al.*, 1997)

	Control	Vegetable fat	Animal fat
Texture:			
Hardness	3,4	2,9	3,6
Juiciness	2,1[b]	3,0[a]	2,9[a]
Chewiness	4,0	3,8	3,9
Fibrousness	2,6	2,5	2,7
Flavour:			
Aniseed	2,3[a]	2,3[a]	1,5[b]
Grass	3,4[a]	3,4[a]	2,8[b]
Liver	1,1[b]	1,2[b]	1,9[a]
Sweet	2,1	2,0	1,8

perirenal fat of rabbits transferred from the mixture of oil (including rapeseed oil) added to the experimental diet (RAIMONDI *et al.*, 1974b). Concerning intramuscolar fat, the inclusion of a mixture of high-PUFA vegetable oils in the diet increased the concentrations of linoleic and linolenic acids and reduced those of palmitic and palmitoleic acids (RAIMONDI *et al.*, 1974b). When adding beef tallow, higher concentrations of meristic and palmitic acids and lower concentrations of oleic and linoleic acids were found in the *longissimus dorsi* muscle compared to the addition of vegetable oils (RAIMONDI *et al.*, 1975; COBOS *et al.*, 1993).

The FA profile of rabbit meat and fat deposits does not exactly reflect the FA profile of the dietary source of fat (COBOS *et al.*, 1993; OLIVER *et al.*, 1997; GONDRET *et al.*, 1998) even if the former is always highly influenced by the latter (LOPEZ-BOTE *et al.*, 1997). Moreover, the influence of dietary FA composition seems to be more pronounced on separable fat than intramuscular fat composition.

The reason for modifying FA composition in rabbit meat is linked to the role played by intramuscular lipids in the organoleptic properties of meat (GONDRET, 1998). OUHAYOUN *et al.* (1986a) demonstrated that 5% addition of different fat sources (olive, cacao, linseed and copra) modified the melting point of perirenal fat and the sensory properties of rabbit meat. The addition of olive oil and cacao fat did not modify the sensory appreciation of rabbit meat, while the meat of rabbits fed with copra or linseed oil proved unacceptable: the former presented a "soap" taste due to the high concentration of lauric acid; the latter had a rancid and acid taste caused by the peroxidation of the PUFA present in high amount, especially linoleic acid.

Table 9 : Effect of storage method and vitamin E addition on rabbit meat characteristics (DAL BOSCO and CASTELLINI, 1998).

	7 days at 4°C		30 days at –18°C	
	Control	Vitamin E	Control	Vitamin E
Lipid quality:				
PUFA n-3 (% total FA)	3.03[a]	4.19[b]	3.58[a]	4.37[b]
TBARS index (µmol MAD/kg)	8.54[C]	3.05[B]	2.98[B]	1.48[A]
Technological properties:				
pH	5.81[B]	5.88[B]	5.53[A]	5.60[A]
Water holding capacity (%)	57.02[Bb]	58.37[Bc]	55.41[Aa]	56.55[Ab]
Storage losses (%)	0.99[B]	0.62[A]	1.58[C]	1.08[B]
Cooking losses (%)	33.92[b]	32.23[a]	35.18[c]	33.98[b]
Colour parameters:				
L*	61.12[b]	60.71[b]	57.46[a]	57.81[a]
a*	5.83[C]	5.07[B]	4.37[B]	3.18[A]
b*	1.49[c]	1.25[b]	1.08[b]	0.85[a]

OLIVER *et al.* (1997) reported significant differences in the organoleptic traits of the *longissimus dorsi* muscle of rabbits fed enriched-fat diets. Regardless of source, dietary fat inclusion resulted in higher meat juiciness due to greater fat concentration. Moreover, the addition of animal fat gave a "liver" taste to the meat, while vegetable fat provided an "aniseed" flavour (Table 8).

The addition of vegetable and animal fat to the diet affected the colour and consistency of both perirenal fat and meat, with the former being darker and softer, and the latter less pale compared to a control diet (PLA and CERVERA, 1997). Other technological characteristics of meat were also modified by the dietary fat, which increased the water holding capacity and the ultimate pH of the *longissimus dorsi* muscle.

The high PUFA concentration in rabbit meat also affects its suitability for transformation and storage due to their high susceptibility to peroxidation and going rancid, and highly unsaturated dietary fat are likely to favour the oxidation of meat and meat products (LIN *et al.*, 1989). LOPEZ-BOTE *et al.* (1997), however, found a higher degree of oxidation in the meat of rabbits fed diets not enriched in fat than those fed diets that included olive or sunflower oils. This effect was attributed to the enrichment of the meat in oleic acid (C18:1, n-9) with the olive-oil diet, or in linoleic acid (C18:2, n-6) with the sunflower-oil diet, while the meat of rabbits fed diets not enriched with fat presented the highest proportion of linolenic acid (C18:3, n-3). Some studies report a higher oxidation susceptibility of (n-3) PUFA than (n-6) PUFA (HU *et al.*, 1989; LOPEZ-BOTE *et al.*, 1997).

In view of the economic convenience of increasing dietary DE concentration through fat addition, and having assessed the effect of fat addition on the FA composition of rabbit meat, the need to prevent and limit the oxidation processes assumes fundamental importance. The addition of antioxidants like vitamin E have been largely studied in other species but less tested in rabbits. BERNARDINI *et al.* (1996) demonstrated the antioxidant capacity of plasma in rabbits fed a diet supplemented with 200 mg/kg of vitamin E, and recorded higher PUFA levels in the *longissimus dorsi* muscle. The addition of vitamin E did not modify the relative FA concentration in the *longissimus dorsi* muscle but reduced the susceptibility to oxidation when the meat was stored under commercial conditions (LOPEZ-BOTE *et al.*, 1997). DAL BOSCO and CASTELLINI (1998) studied the effect of vitamin E supplementation on the quality of rabbit meat after 7 days of storage at 4°C and 30 days of freezing at -18°C. The addition of vitamin E preserved the oxidation of PUFA for both storage methods, by reducing TBARS index (Table 9). Besides, it resulted in a lower water holding capacity of meat and lower water losses during cooking and affected the colour of the *longissimus dorsi* muscle caused by decreased myoglobin oxidation and FA lipolytic processes. However, due to the high cost of vitamin supplementation, the economical advantage of using high dietary levels of vitamin E to reduce meat oxidation has not yet been demonstrated.

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