RECENT RESEARCH ADVANCES IN RABBIT NUTRITION

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INTRODUCTION

During the ten last years, the techniques of feeding (manufacture, adapted formulation...) and the recommendations for rabbit nutrition have strongly evolved, in order to obtain a better adjustment between feed's composition and needs of the animals, according to their physiological stage. Quite all the information available is related with meat rabbit nutrition and we will limit the present paper to this type of production. For Angora rabbits, a synthesis was made recently (LEBAS et al., 1998a), but the basic international information is scarce, and for many nutritional aspects, reference to recommendations for meat rabbit could be suggested as the bet solution for Angora nutrition.

In the present paper, the intention is not to summarise the whole of recent progress in rabbit nutrition, knowing that a book on the nutrition of the rabbit was published in 1998 (DE BLAS and WISEMAN, 1998). In addition, some more recent reviews of different parts of rabbit nutrition were published in periodic publications (GIDENNE, 2000a; LEBAS, 2000a, b), at the occasion of the 7th World Rabbit Congress held in Spain (CARABAÑO et al., 2000; FERNANDEZ CARMONA et al., 2000) or at the occasion of some other recent international meetings (GIDENNE, 2000b, De BLAS and GUITÉRREZ, 2000). We will only try to present some aspects of the recent progress, which we consider significant in the field of the rabbit nutrition.

SUITABLE METHODS for FEED DIGESTIVE EFFICIENCY MEASUREMENT

We would first mention a recent effort of standardisation of measurements of faecal apparent digestibility (PEREZ *et al.*, 1995), within the framework of the European research group EGRAN (GIDENNE, 1999). This standardisation of measurements, currently limited to *in-vivo* measurement of the dry matter digestibility, should be implemented by recommendations on major nutrient analyses. The main recommendations are to estimate feeds digestibility with 7-8 weeks old rabbits fed *ad libitum.* It is recommended to work with a minimum of 8 rabbits per tested feed and to collect all faeces excreted during 4 consecutive days, after one week of adaptation.

The overall digestion of a feed does not seem affected by the genetic type of growing rabbit (PEREZ *et al.*, 1999). On the other hand, the digestion in the doe is lower (-3 to -5 units) than that of the growing rabbit (PEREZ *et al.*, 1996a), and this could depend on the energy level of the diet. Consequently, if the digestion of a diet adapted to lactating females is determined on growing rabbits, that would lead to an overestimation of the level of digestible nutrients. Similarly, if the needs of the females are determined from their performances, we overestimate their requirement in digestible nutrients, if the latter are calculated from growing digestibility values. That reinforces the need for expressing the requirements in digestible nutrients (table 1), but obtained with appropriate measurements.

REQUIREMENTS IN PROTEIN AND ENERGY

The protein and energy needs of the breeding doe are relatively high, in particular when simultaneously pregnant and lactating (XICCATO, 1996). However, since work of MAERTENS and DE GROOTE (1988), the recommendations in term of relative supply in digestible protein (DP) compared to digestible energy (DE) are unchanged. Ratios of 12.5 g and 11.0 g DP/MJ of

Table 1 : Requirements in energy, protein and in some major amino acids.
(as concentration per kg of raw feed, corrected for a dry matter content of 900 g/kg)

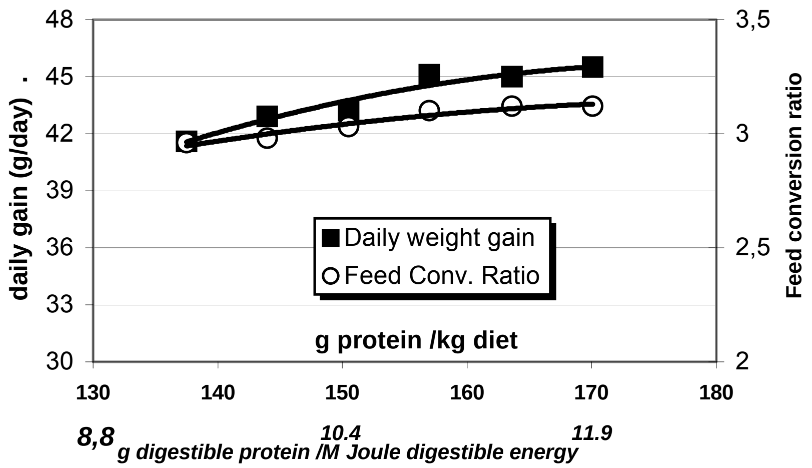
		Fattening rabbits		Breeding does		
	Unit	**Post weaning** (till 45d of age)	**End of fattening**	**Young Does**	**Intensive rhythm**	**Semi-Intensive**
Digestible Energy	*kcal/kg*	*2250-2350*	*2350-2450*	*2150-2250*	*2600-2700*	*2500-2600*
(DE)	Mjoules/kg	9.4-9.8	9.8-10.3	9.0-9.4	10.9-11.3	10.5-10.9
Crude protein	*g /kg*	*≥ 155*	*150-155*	*145-150*	*180-190*	*175-180*
Digestible protein	g / kg	≥ 115	110-115	100-110	130-140	125-130
"DP" (Nx6.25)	g/MJ DE	12.0-12.5	11.5-12.0	10.5-11.5	11.8-12.5	10.5-11.5
Lysine						
total (crude)	g/MJ DE	*≥ 0.78*	*≥ 0.70*	≥ 0.70	*0.61-0.69*	*0.64*
digestible		≥ 0.62 (1)	≥ 0.52 (1)	≥0.50 (1)	0.44-0.50 (2)	0.46 (2)
Methionine+ Cystine						
total (crude)	g/MJ DE	*0.67-0.80*	*0.60-0.70*	≥0.60	*0.49-0.59*	*0.49-0.51*
digestible		0.50-0.60 (3)	0.45-0.52 (3)	≥0.45 (3)	0.36-0.43 (4)	0.36-0.38 (4)
Threonine						
total (crude)	g/MJ DE	*0.62-0.66*	*0.55-0.60*	≥0.55	*0.56-0.61*	*0.58*
digestible		0.42-0.45 (5)	0.37-0.41 (5)	≥0.37 (5)	0.37-0.41 (6)	0.38 (6)

1): digestibility estimated to 74% ; (2): digestibility estimated to 72% ; (3): digestibility estimated to 75% ; (4): digestibility estimated to 73% ; (5): digestibility estimated to 68%; (6): digestibility estimated to 66% .

digestible energy are proposed, respectively for an intensive rhythm of reproduction and a less intensive one (table 1). The impact of the source of energy (lipids *vs* starch) on the gestation and lactation was specifically treated by FORTUN-LAMOTHE *et al.* (1999). It must be emphasised that lipid addition to the rabbit doe diets (animal fat or oil) improves the milk production but simultaneously decreases the body reserves of the doe. On the contrary, for a same DE level, increase of the starch content reduces the milk production, but favours the body reserves deposition as measured at the end of the lactation.

The requirements in energy and protein for growth depend on several factors, such as the weight at weaning and the growth rate. Since the studies of DE BLAS *et al.* (1981, 1985), few works were devoted to the relationship between energetic and protein supply. A supply of 10g DP/MJ DE had then been defined for optimal performances, but the growth rate was lower than 40g/d. Presently, a commercial feed often presents a higher ratio DP/DE (11.5 to 12.5). More recent works suggest that below 11 g DP/MJ DE the growth rate is depressed (MARTENS and LUZI, 1997). But this reduction is small and may be associated with an improvement of the feed efficiency (figure 1).

Figure 1 : Average growth rate and feed conversion ratio of rabbit fed, between 32 and 74 days of age, diets with increasing concentration of proteins but with a constant level of digestible energy (10.4 MJ/kg) (Maertens and Luzi, 1997)



Nevertheless, it is now necessary to validate these recommendations for new rabbit hybrid lines, having a higher growth rate (meanly between 45 and 50g/d) particularly during the post-weaning period, when the rabbit fully expresses its growth potential (> 50g/d). MAERTENS *et al.* (1997, 1998) show that the reduction of ratio DP/DE mainly affects the growth during the 3 weeks after weaning. Moreover, it confirms that the nitrogen retention increases with the protein dilution of the diet, and thus reduced the nitrogen excretion. According to MAERTENS, it seems possible to reduce the protein supply in finishing rabbits (from 12.5 to 11.5 g DP/MJ DE), without increasing the fatness of the carcasses, nor affecting the performance. It could thus lead to a significant reduction of nitrogen output (-10%) in the environment.

On the other hand, very few studies concerned the effects of the ratio DP/DE on digestive pathology and mortality in fattening rabbits.

AMINO ACID REQUIREMENTS

Revised recommendations for the major amino acids (AA) were proposed recently by Madrid University (team of Prof. DE BLAS). The methodology was based on an evaluation, for female and growing rabbits, of the same dietary model (range of AA supply), relatively rich in digestible energy (10.7 MJ/kg). But the basal diet formulation was adapted to the lactating female (intensive reproduction rhythm). This can present a disadvantage in estimating the needs with a level of ingestion relatively low for the growing rabbit, and thus to over-estimate slightly the requirements. Indeed, if the dietary concentration in digestible energy is weaker, the ingestion of the animal would be higher, as would be its ingestion of AA. Thus it would be advisable to recommend a lower dietary level of AA, in proportion of the rise of the feed intake; or as suggested a lot of years ago (COLIN et ALLAIN, 1978; LEBAS 1983) requirements must be expressed in grams of AA/MJ digestible energy as presented in table 1.

Similarly, in these studies feed digestibility was measured only on growing rabbits (live-weight = 1.6-1.8 kg), having a higher digestive efficiency (+3 to +5 units) than that of females (PEREZ *et al.*, 1996a). The requirement in digestible AA estimated here for the females is in fact probably slightly lower.

We thus presented in the table 1 recommendations, which take account of the previous remarks. Furthermore to be consistent with the recommendations for digestible protein, and to avoid excess or deficiency in the real intake of AA, we proposed to use for AA the following unit: grams per Mega-Joule digestible energy.

The optimum lysine level was estimated to be between 0.71 and 0.76 g/MJ DE to maximise the growth rate and feed conversion (TABOADA *et al.*, 1994). The authors proposed a lysine recommendation of 0.75 g/MJ DE (raw basis), if the digestibility of lysine is 74% (synthetic acid amino equal to 15% of the total, i.e. a crude protein digestibility of approximately 70%). The authors pointed out that it is preferable to express this requirement using digestible lysine and recommended a supply of 0.59 g digestible lysine/MJ DE in the feed.

For the breeding doe the requirement in digestible lysine was estimated at 0.52 g/MJ DE (0.68 g of crude lysine) to obtain maximum reproductive performance (e.g. kits weaned per doe/perlitter) (TABOADA *et al.*, 1994). In addition, the authors showed that at levels between 0.64 and 0.76 g of crude lysine /MJ DE , the milk production increased noticeably as well the litter weight (at 21d.). If we would promote a high milk production and a high litter weight for females in intensive reproduction rhythm, these data indicate to retain an optimum crude lysine level of 0.75 g/MJ DE (i.e. 4.1% of rough proteins). It is lower than the level of 0.84 g/MJ DE proposed by DE BLAS and MATEOS (1998), as well as at the level of 0.85 g/MJ DE proposed by XICCATO (1996) or of 0.90 g/MJ DE (5% of rough Proteins) proposed by MAERTENS and DE GROOTE (1988).

The requirements in sulphur amino acids (SAA) were evaluated by TABOADA *et al.* (1996) using a range from 0.48 to 0.72 g SAA /MJ DE (with at least 50% synthetic methionine in this experiment), and adapted for females in lactation (10.76 MJ DE/kg). For the female, the needs are estimated to be 0.64 g crude SAA /MJ DE (0.49 g digestible SAA, with a digestibility coefficient of 75%), when maximum productivity is the aim (without differential effect on the milk production or on the reproduction performances). However, the increase in productivity is weak beyond a rate of 0.54 g of SAA /MJ DE (0.40 g digestible SAA), which is a lower level than that of 0.62 g/MJ DE proposed by MAERTENS (1996).

For the growing rabbit, the minimum need for SAA would be 0.64 g/MJ DE (TABOADA *et al.*, 1996). However a favourable effect on the growth rate was observed with the addition of SAA till the maximum rate tested in this study (either 0.58 g of digestible SAA /MJ DE). This effect was more marked during the 2 weeks following weaning, thus stating that the requirement in SAA would be lower for finishing growing rabbit. The effect of the age was confirmed by the recent study of MAERTENS *et al.* (1998), indicating a greater sensitivity of the young rabbits to low protein diet, during the post-weaning period. These recommendations in SAA are close to those (0.62 g/MJ DE) previously proposed for the growing rabbit by BERCHICHE and LEBAS (1994).

The requirements in threonine were evaluated using range of 5 diets containing 0.54 to 0.72 g of crude threonine /MJ DE (DE BLAS *et al.*, 1998). Reproductive performance evolved quadratically with the dietary threonine level, i.e. for a too high level (0.72 g/MJ DE) a reduction of the performances was observed. The minimum threonine requirement was estimated to 0.63 g/MJ DE (0.43 g digestible). However, a slight rise of productivity was observed until a rate of 0.68 g/MJ DE. These values were slightly lower than the level of 0.70 g/MJ DE suggested by LEBAS (1989).

The growth rate of fattening rabbits answers also according to a quadratic rule with the rate of threonine, and there was no more improvement beyond a level of 0.63 g/MJ DE (digestible 0.43 g) (DE BLAS *et al.*, 1998). The optimum need in crude threonin was thus estimated at 0.60 g/MJ DE (digestible 0.40 g). It is slightly higher than the level of 0.55 g/MJ DE proposed by LEBAS (1989), but similar to that proposed in 1996 by BRIENS (0.60 g/MJ DE or 3.75% of crude protein). Moreover, BRIENS (1996) indicates that the addition of synthetic AA, highly digestible, led to better performances. This confirms the need for expressing the requirements in digestible nutrients.

FIBRE REQUIREMENTS

The digestion of fibre in the rabbit was subjected to several recent reviews (GIDENNE, 1996; GIDENNE *et al.*, 1998d; DE BLAS *et al.*, 1999), as the dietary fibre supply is implicated in the prevention of the digestive disorders (GIDENNE, 1997). However, the favourable effect of fibres with respect to resistance to pathogenic agents was clearly shown only recently (LICOIS and GIDENNE, 1999). In 2000, the same team has also clearly demonstrated the interaction between the initial health status of the animal (SPF vs conventional) and the reaction to low fibre feeds: the higher the initial health status, the lower the digestive disorders frequency (BENNEGADI *et al.,* 2000)

On the other hand, a high fibre supply leads to an energy dilution of the diet. The animal thus attempts to increase its feed intake to satisfy energetic needs, and the feed conversion is reduced. When the dietary fibre level is very high (>25% ADF), the animal cannot increase its intake sufficiently to meet its energetic needs, thus leading to a lower growth rate.

Dietary fibres correspond to several components (belonging mainly to the plant cell wall), whose analysis remains difficult (GIDENNE *et al.*, 1998d). The sequential procedure of VAN-SOEST *et al.* (1991), officially recognised by AFNOR (1997), presents the advantage of estimating several fibrous fractions from only one sample, such as hemicelluloses (NDF-ADF), cellulose (ADF-ADL) and lignins (ADL). Although biochemically imperfect, these criteria have the advantage of a rather good reproducibility for a classical laboratory in feedingstuffs analysis. The interest of these criteria to establish fibre recommendations for the growing rabbit (table 2) was addressed by recent studies, which we present below, and which take into account the quantity, nature and the botanical origin of fibres.

Table 2 : Requirements in fibre and starch (as concentration per kg^{-1} of raw feed, corrected to a dry matter content of 900 g/kg^{-1})

	Unit	Fattening rabbits		Does	
		Post weaning (till 45d of age)	**End of fattening**	**Young does**	**Breeding does**
Lignocellulose "ADF"	g	≥190	≥170	*> 200*	*>140*
Lignins "ADL"	g	≥55	≥50	*?*	*?*
Cellulose "ADF-ADL"	g	≥130	≥110	*?*	*?*
Ratio Lignins/ Cellulose		>0.40	>0.40	*?*	*>0.30*
Hemicelluloses "NDF-ADF"	g	>120	>100		
DF/ADF		≤1.3	≤1.3	*?*	*?*
Starch	g	<140	≤180	*?*	*?*

Fibre requirements are established mainly for preventing digestive troubles of the growing rabbit, and also for improving performances of does. They have been validated on growing rabbits with a feed intake of 90 to 120 g/d in post-weaning period, and 120 to 160 g/d in finishing period.
ADF : Acid Detergent Fibre ; ADL : Acid Detergent Lignin (Van-Soest *et al.*, 1991 ; AFNOR, 1997; séquential procedure).
DF : digestible fibres (pectins + hemicelluloses).

The need of fibre is more particularly expressed during the post-weaning period. Low fibre intake, without variations of fibre nature or origin, involves lower growth rate during the 2 weeks after weaning (GIDENNE and JEHL, 1999; PINHEIRO and GIDENNE, 1999) that are often associated with intake troubles or digestive disorders.

The botanical origin of fibres can influence digestion and cæcal microbial activity, independently of the quantity or the nature of fibres. Thus, supplying fibre from a single botanical origin (e.g. wheat: straw + bran) does not favour caecal fermentations nor the health status (GIDENNE *et al.*, 1998c). This situation is however unusual in rational breeding, where the rabbits received pelleted feeds containing plants of diversified origin.

To take into account the nature of fibres and the interactions with starch, it is necessary to respect four points (see table 2):

1. the minimum quantity of lignocellulose (ADF).
2. the quality of lignocellulose, i.e. the lignins ratio / cellulose.
3. the quantity of digestible fibres (DF = hemicelluloses and pectins) compared to lignocellulose (low digestible fibres), by calculating the ratio " DF/ADF ".
4. the quantity and the nature of the starch (particularly during the period around weaning).

1. Requirements of lignocellulose (ADF) : impact of the quality of ADF.

The favourable effect of ADF supply on the frequency of the digestive disorders and mortality in fattening rabbits was shown by MAÎTRE *et al.* (1990) using an adequate experimental design (380 rab./diet, in 5 sites). More recently, and with a similar design, GIDENNE *et al.* (1998b) showed that the health risk (HR = mortality + morbidity) increased from 18 to 28% when the dietary ADF content decreased from 19 to 15%.

However, in a second step to improve fibre recom-mendations, the following question was examined : is a single criterion, such as the supply of lignocellulose, be sufficient enough to define the fibre contributions and the " level of security " of a feed for the growing rabbit ? Apart from the quantity of lignocellulose, other studies attempted to specify the effects of the quality of the ADF, i.e. the respective effects of lignins and cellulose (according to the Van-Soest procedure).

The nutritional role of the lignins was first addressed (GIDENNE and PEREZ, 1994; PEREZ *et al.*, 1994). The intake of lignins (criterion ADL = Acid Detergent Lignin) involves a sharp reduction of the feed digestibility (see figure 1, slope = - 1.6), associated with a reduction of the digesta retention time in the whole tract (-20%), and with a rise of the feed conversion ratio. On this last point, the botanical origin of lignins seems to modulate the effects observed. In parallel, a linear relationship (R^2=0.99; fig.1, n=5 feeds) between a chemical criterion of the plant cell wall (ADL) and mortality in fattening (by diarrhoea) were outlined for the first time (without major effect of the botanical origin of lignins). The favourable effect of the dietary ADL level on the HR was then confirmed with other experiments, as indicated in figure 2 (R^2=0.79; n=11 diets).

The effects of cellulose intake are less important than for ADL, regarding the decrease of the digestibility (see fig.1: slope = -1) or that of retention time (GIDENNE and PEREZ, 1996; PEREZ *et al*., 1996b). The cellulose also favours the health status, but compared to lignins, the effects seems less important. These two components of lignocellulose exhibit similar effects for the prevention of the digestive disorders in rabbit. But, a major role is attributed to lignins, since the reduction of the ratio lignins/cellulose (L/C) involves a rise of the digestive disorders, as shown recently by GIDENNE *et al.* (1999a). Furthermore, when the ratio L/C is lower than 0.4, a reduction of the growth rate (-5%) and a higher digesta retention time are observed. Similarly, for the doe, a recent study (NICODEMUS *et al.*, 1999) showed a favourable effect of a linear rise of the ratio L/C (from 0.14 to 0.31) on the dairy production of the females and on the litter weight.

Globally, the lignins requirement (ADL) for the growing rabbit, can be assumed as to 5 to 7g/d, and that out of cellulose (ADF-ADL) from approximately 11 to 12 g/d.

By comparing mixtures of fibre sources, we observed that the botanical origin of lignins (figure 1) could affect the feed conversion, but would not have a major effect on mortality by diarrhoea. However, to date, no correct and quick analytical method for lignins is available. Consequently, estimating the amount of lignins in a raw material remains difficult, particularly in tannin-rich ingredients (grape marc, etc.), and caution must be taken to fit requirements with such ingredients.

2. Effects of fibre fractions more digestible than lignocellulose.

A third step in evaluating the fibre requirements for growing rabbit was to test the following hypothesis: apart from quantity and quality of ADF, is it necessary to specify the effects of more digestible fibres, such as hemicelluloses and pectins?

Digestible fibres "DF" fraction could be estimated by the sum of the two fractions hemicelluloses (NDF-ADF, according to the sequential procedure of VAN-SOEST) and water insoluble pectins (GIDENNE, 1996). The procedure of analysis of pectins remains complex, it is nevertheless possible to estimate their value in ingredients from tables (IO7, 1993; BACH KNUDSEN, 1997). Compared to lignocellulose, the DF fraction is highly digested by the rabbit (35 to 50%, GIDENNE, 1997).

As shown in figure 3, a large variation (20 to 50%) of the health risk "HR" (JEHL and GIDENNE, 1996) was observed according to the ratio DF/ADF, and with a constant ADF level (± 20%). This confirmed that fibre requirement cannot be fulfilled only through requirement in lignocellulose.
On the other hand, for diets with a ADF level over 15%, we observed a very close relationship (R^2=0.88) between the rise in ratio DF/ADF and the HR (figure 4). It would thus be advisable to maintain a ratio DF/ADF lower than 1.3.
Besides, when starch is substituted by DF, the growth performances (i.e. feed conversion, growth rate) are not greatly affected (JEHL and GIDENNE, 1996; GIDENNE *et al.*, 1998b) ; illustrating that digestible fibres are efficiently utilised by the growing rabbit.

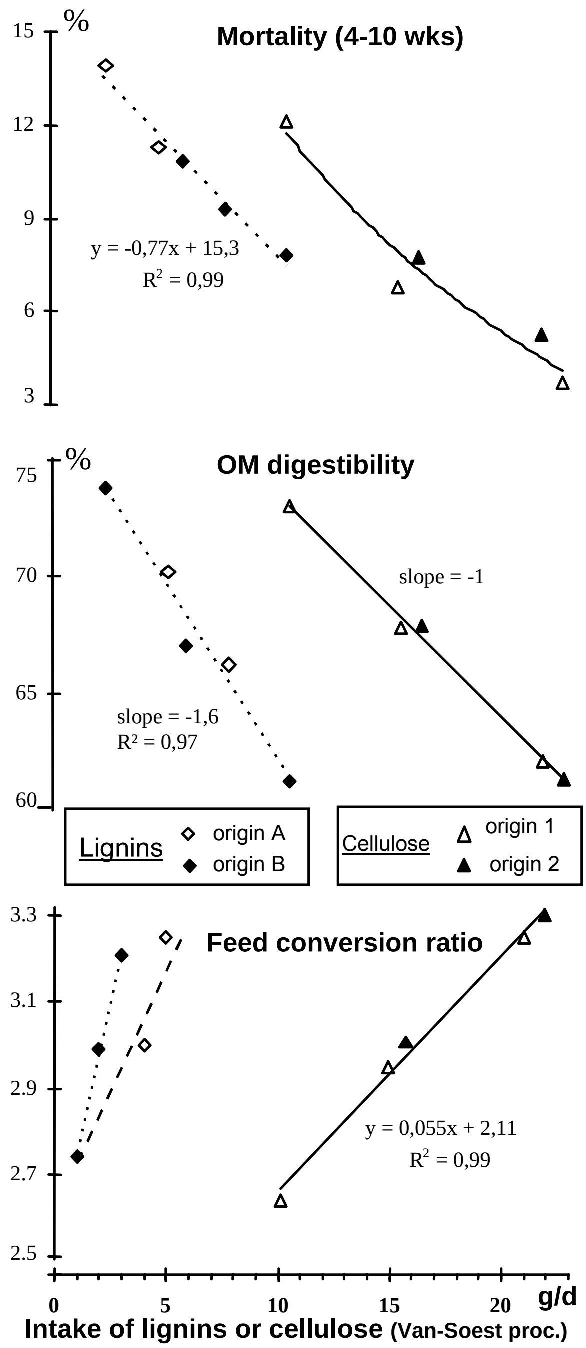
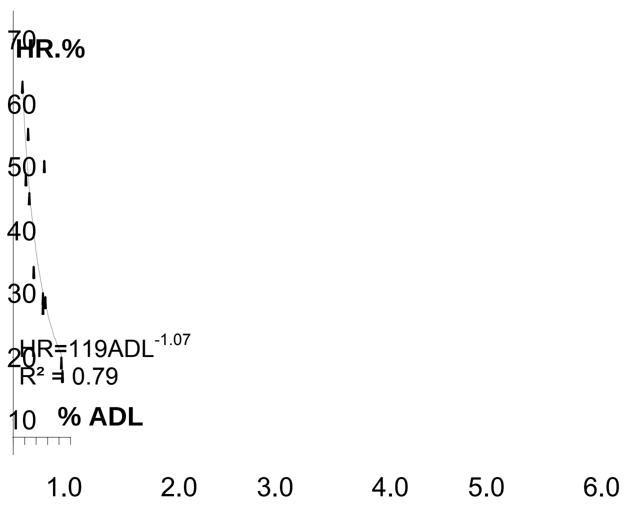


Figure 1 : Nutritional role of lignins and cellulose in the growing rabbit. (GIDENNE *et al.*, 1998b)



(HR= Mortality + morbidity rate, measured from 28 to 70d of age, on at least 40 rabbits/diet; one point = one diet) ; (Gidenne et Jehl, 1999; Pinheiro et Gidenne, 1999; Gidenne et al., 1998b).

Figure 2 : Health risk "HR" according to dietary lignin (ADL) level.

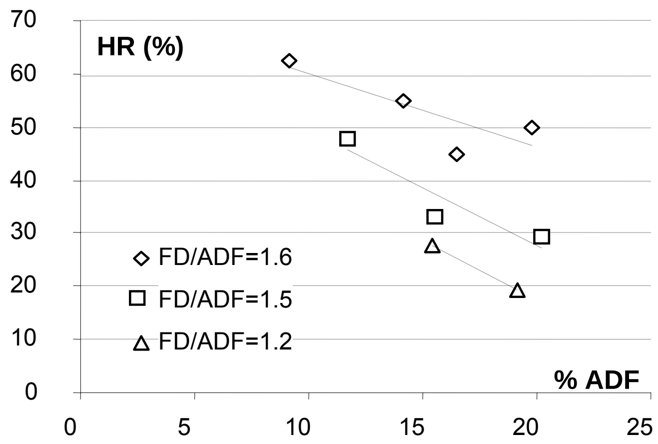


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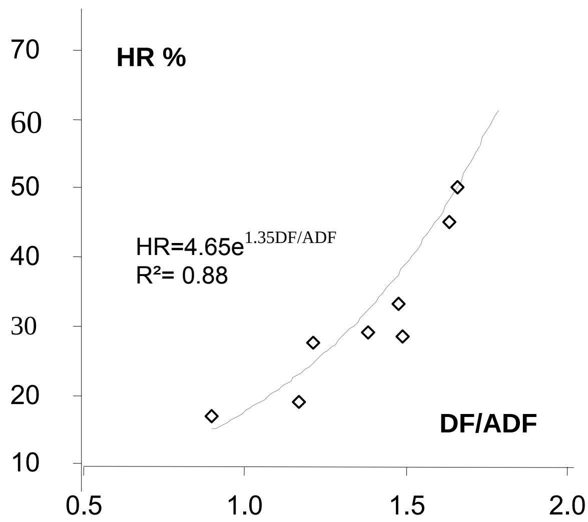
Figure 3 : Health risk "HR" according to dietary lignocellulose (ADF) level, in 3 experiments



DF : digestible fibre = pectins + hemicelluloses (NDF-ADF) ; ADF = lignocellulose.
(HR= Mortality + morbidity rate, measured from 28 to 70d of age, on at least 40 rabbits/diet; one point = one diet) ; (Gidenne et Jehl, 1999; Pinheiro et Gidenne, 1999; Gidenne et al., 1998b).

Figure 4 : Health risk "HR" according to the ratio DF / ADF (and ADF>15%)

3. Effects of starch supply , interaction with fibre supply.

A fourth step in the evaluation of fibre needs, was to estimate if starch supply could interact or not with fibre supply (particularly ADF). For diets respecting the preceding constraints (> 18% ADF and DF/ADF < 1.3), the starch substitution (24 to 12%) by digestible fibres " DF " (ratio hemicelluloses / pectins = 75/25), led to a decrease in mortality after weaning (from 10.1 to 4.6%; GIDENNE *et al.*, 1998b). This mortality associated to an excessive starch supply was higher during the post-weaning period. It would thus be advisable to respect in diets a starch level lower than 14% during this period. Recently, GIDENNE *et al.* (1999) estimated that the starch ileal flow in finishing growing rabbit remained very weak (<2g/d), even for high starch level (30%). At the end of the fattening period, the starch supply would be thus only a secondary factor in the determinism of digestive disorders, the major factor remaining the fibre intake.

It has also been hypothesised that incorporating resistant starch in feeds would favour enteritis. However, when comparing iso-ADF feeds (16.5% ADF) having starch from maize or from wheat, only a slight reduction (P=0.25) in mortality was registered for "wheat" (5.6%, with 518 rabbit per diet) compared to "maize" diet (8.5%). But in accordance with the initial hypothesis, the utilisation of a more resistant starch such crude potato starch, clearly depressed the health status of the growing rabbits (PINHEIRO and GIDENNE, 2000)

EFFECTS OF FEED PARTICLE SIZE.

Since the work of BJÖRNHAG (1972), we know that in period of hard faeces excretion, the proximal colon act as a sieve: largest particles (diam. >0.3mm) being excreted in hard faces, whereas finest one are driven back towards the caecum. Thus, it is acknowledged that the particle size distribution of a feed could affect the digestive motility and more particularly the cæcal physiology (transit, pH, fermentative activity, development of the caecal wall, etc.).

The measurement of the particle size distribution must be performed after the pelleting stage, since pelleting largely modifies the size of particles (LEBAS and LAMBOLEY, 1999). Such a measurement would improve the nutritive evaluation the sources of fibre, as suggest by GARCIA *et al.* (1999). However, the diets used in this study were very atypical, since the sources of fibres were incorporated at a high level (60 to 75%). It would thus be advisable to confirm these assumptions using more classical dietary model.

A fine grinding (screen size ≤ 1mm) of the raw materials leads to longer retention time (LAPLACE and LEBAS, 1977; GIDENNE *et al.*, 1991), but are not associated with a rise in feed digestibility (LEBAS *et al.*, 1986; GIDENNE and SCALABRINI, 1990), nor with a negative effect on the health status. Only a very fine grinding (screen size = 0.25mm) led to a significant rise of digestibility (LAPLACE and LEBAS, 1977).

More recently, the effects feed particle size on the digestion and on the performances of growing rabbit were studied, by comparing feeds with different particles size obtained through a controlled choice of ingredients, and without changes in grinding procedure (NICODEMUS *et al.*, 1997a,b). However, in these experiments, the feed composition changed parallel to the particle size profile, making the interpretation of the results difficult. We can however mention that a variation from 18 to 24% of the level of coarse particles (>0.315mm) does not significantly affect mortality rate in fattening period. On the other hand, when this rate is lower than 18% (and although the rate of ADL is 6.1%), a reduction of the dairy production of the females is observed, associated with a lower litter weight at weaning and to a lower post-weaning growth rate.

Compared to a standard grinding (3mm holes), a coarser one (8mm) does not affect performances or digestion (DIAZ ARCA *et al.*, 1989). Thus only a very low rate of large particles would have a negative impact on the performances. Nevertheless, a rate of coarse particles lower than 25 % is very improbable in practice, since on a series of 77 commercial feeds the average proportion of coarse particles is 38.8% (minimum = 22.7%, mean minus 2 sd = 27%; Lebas 1999). Moreover, it is unlikely to meet a real excess in fine particles, knowing that a fine grinding of ingredients is relatively expensive (energy cost, rise of "fines"...). It thus does not seem necessary to propose a recommendation in term of size of particles, at least for standard commercial pelleted feeds (LEBAS, 2000a).

FAT ADDITION AND INTERACTIONS WITH FIBRE SUPPLY.

For the growing rabbit, adding fat in the feed aims to increase the level of digestible energy, without reducing the fibre level. It is an approach for reducing the antagonism between growth performances and health risk. The EFFECTS OF THE FAT ADDITION WERE REVIEWED RECENTLY (DE BLAS AND MATEOS, 1998; MAERTENS, 1998B, FERNANDEZ-CARMONA et al., 2000). We can outline that adding fat in iso-NDF feeds (but with a rise of the digestible protein " DP ", such as ratio DE/DP remains constant) has a favourable effect on digestion of energy and on the feed efficiency.

However, in parallel, the animals reduce their feed intake so that growth rate is not improved, and the carcass fatness is increased.

FALCAO E CUNHA *et al.* (1998, 2000) indicate a positive interaction between fat addition and the digestion of hemicelluloses (NDF-ADF). For diets rich in fibre (ADF>20%), a strong fat addition (up to 7%) reduced the feed intake only slightly, and thus led to a rise in DE intake and performances. However, MAERTENS *et al.* (1998) showed with iso-energetic feeds, that starch substitution by lipids (4 to 4.5% of the diet) would affect moderately the growth performances, but resulted in a rise of the carcass fatness, as shown previously by OUHAYOUN (1986). Nevertheless, in the case of moderate fat addition (≤ 3%), XICCATO *et al.* (1998) showed that DE intake remain unaffected, but feed conversion is improved without changes in carcass fatness.

To our knowledge, only FERNANDEZ CARMONA *et al.* (1998) studied the impact of dietary fat addition, in interaction with fibre supply, on the health status of growing rabbits. Results showed that fat addition in alfalfa rich diets (88%) reduced mortality, without a major fall of the performances compared to a standard commercial feed. However, further studies are necessary to confirm these results, particularly with more classical dietary model.

Fat addition in doe feeding is now widespread, because it allows an increase of the DE intake and milk production, but it failed to reduce the negative energy balance of the primiparous doe simultaneously pregnant and lactating (FORTUN-LAMOTHE, 1997; FORTUN-LAMOTHE *et al.*, 1999). From several recent studies as previously mentioned, we can retain that fat addition leads to a rise in the milk production and to a modification of the chemical composition of milk (higher level of dry matter and energy). In addition, the fatty acids profile of milk is affected by the nature of the dietary fat. On the other hand the effects of fat on prolificity seems not reliable according to authors.

PASCUAL *et al.* (1998, 1999) studied the barley replacement by vegetable oils or animal fat, for feeds with up to 10% fat. As feed intake was unchanged, the DE intake increased, resulting in higher body reserves, a higher milk production, a rise of the litter weight at weaning (+400g), and a reduction of mortality before weaning. On the other hand, a negative effect on mortality of kits was observed by Lebas & Fortun-Lamothe (1996), with iso-energetic diets having a high-fat content, compared to a high-starch content.

The nutritional preparation of the female before mating (i.e. flushing) appears an interesting way to support the performances of reproduction (fertility etc., FORTUN-LAMOTHE, 1998; MAERTENS, 1998a; FORTUN-LAMOTHE *et al.*, 1999; LUZI *et al.*, 1999). In the same way, the nutritional preparation of the young doe (before the first mating) seems of interest for improving the body reserves and the performances of the doe. For instance, between weaning and the first kindling, feeding the young doe with a high fibre diet would increase the body reserves at the end of the first lactation (XICCATO *et al.*, 1999). This confirms the results of NIZZA *et al.* (1997) showing that a fibre rich diets given to young does (between 50d of age up to 10 days of gestation) had a favourable effect on the reproductive performances. Besides, the favourable effect of a high fibre feed (18% ADF vs 7% ADF) on the maternal behaviour (quality of the nest) and with the viability of kits should be confirmed (KAMEL *et al.*, 1993).

NUTRITIVE VALUE OF RAW MATERIALS.

Least-cost formulation of complete feed implies use of various ingredients, particularly to cover the fibre requirements. These raw materials are often by-products of the agro-industry (processing of cereals, oilseeds, etc.), and still recently their nutritive value for rabbit were imprecise or not reliable according to studies. Because, methodology for measuring nutritive value of ingredients is heavy and costly, the research group EGRAN (European Group for Rabbit Nutrition; GIDENNE, 1999) undertook a methodological program for evaluating and predicting value for complete feeds and raw materials. A first objective was to elaborate European tables of nutritive values for raw materials. The first release of these tables, based on a bibliographical review was recently published (PEREZ *et al.*, 1998a ; VILLAMIDE *et al.*, 1998), and reports the value in digestible energy, as well as an estimate of the digestion of proteins. On this latter point, the study of VILLAMIDE and FRAGA (1998) presents prediction equations of the protein digestion of feed ingredients, based on an exhaustive bibliographical review.

Dehydrated alfalfa, usually incorporated in rabbit feeds, was thoroughly studied (PEREZ, 1998; PEREZ *et al.*, 1998b). We can outlined that its DE content (on average = 7.66 MJ/kg DM) can be calculated from its crude fibre content (DE kcal/kg DM=3330 - 46.8 CF (%DM) ; r=-0.94), and that it does not vary according to the level of incorporation in feed. Likewise, the digestibility of alfalfa proteins seems moderate (59%). Garcia *et al.* (1995) studied the nutritive value of alfalfa hay, and estimated that the best predictor of the DE content was the NDF content of the hay.

Recently, the nutritive value of brewer's grains (MAERTENS and SALIFOU, 1997) and of Milurex®, a type of industrial wheat bran (PEREZ and GIDENNE, 1997) were specified. The replacement of cereals (corn or barley) by beet pulps was also recently studied, taking into account that this by-product presents a high level of digestible fibre (hemicelluloses + pectins) potentially well utilised by rabbits. The energetic value of beet pulps would vary according to their quality from 8.79 to 11.72 MJ/kg (DE BLAS and CARABAÑO, 1996). Moreover, JEHL *et al.* (1998) show that the DE content would decrease for a high incorporation rate of over 30%. These authors proposed an average DE content of 11.09 MJ/kg, higher than that proposed in the most recent tables (VILLAMIDE *et al.*, 1998), but in agreement with MAERTENS (1990). Several agro-industrial by-products (soyabean hulls, sunflower hulls, paprika meal) were also evaluated by GARCIA *et al.* (1996, 1997a b, 1999), with respect to their effects on rabbit digestion or their DE value.

MINERALS AND VITAMINS

Requirements for minerals were recently analysed by MATEOS and DE BLAS (1998). Very few new information is available in this field. Only the work of LEBAS *et al.* (1998b) could be noticed demonstrating that the phosphorus requirement of growing rabbits may be satisfied with a feed containing only 0.3% of raw phosphorus. In a previous work, the same team have demonstrated that 0.5% of phosphorus are sufficient for the breeding does (LEBAS and JOUGLAR, 1980). Actualised recommendations are summarised in the table 3.

Table 3: Minerals recommendation for growing-fattening rabbits and breeding does (

Minerals	Unit	Growing-Fattening	Breeding does
• Calcium	%	0.90	1.20
• Phosphorus	%	0.30	0.50
• Sodium	%	0.25	0.25
• Potassium	%	0.60	0.90
• Chloride	%	0.30	0.30
• Magnesium	%	0.30	0.40
• Copper	ppm	10	10
• Iron	ppm	50	75
• Zinc	ppm	50	60
• Manganese	ppm	8	15
• Iodine	ppm	0.50	0.30
• Selenium	ppm	0.05	0.05
• Cobalt	ppm	0.25	0.25
• Fluorine	ppm	0.50	0.50

Requirements for vitamins, were recently analysed by LEBAS (2000b). The water-soluble vitamins and vitamin K are normally synthesised by the rabbit's digestive flora and the amounts are sufficient. But in situation of high probability of digestive disorder *e.g*. just after weaning, a dietary supplementation may be advisable. In addition, a vitamin C supplementation (25 to 30 mg per rabbit and per day) can help the animal in stress situation (heat stress, …). This supplementation can be made by inclusion in pelleted feeds, but paying attention to the high susceptibility of vitamin C to high temperature; otherwise the supplementation could be done in the drinking water.

The vitamin A requirement is largely satisfied if the diet contains 10 000 IU vitamin A per kg or 30 ppm of β-carotene. Additional distribution of vitamin A is without interest for the growing rabbits and may be toxic for the foetus in the pregnant does. Recommendation for vitamin D supply is 800 to 1000 IU/kg of diet. If the dietary concentration is greater than 2000 IU/kg, abnormal calcification of soft tissues (aorta, kidneys, …) is generally observed within 4 to 8 weeks. Recommendation for vitamin E supply is 50 mg/kg of complete feed. A diet that contains only 15 mg/kg induced deficiency symptoms (muscular dystrophy, sudden death, troubles of reproduction in both sexes, …). A massive introduction of vitamin E is not toxic (up to 1%) but may improve to the rabbit meat conservation, by reduction of the speed of oxidation of lipids: inclusions of 200 to 300 ppm vitamin E are suitable.

The information available on vitamins requirements is too scarce to propose recommendations for the different physiological stages (LEBAS, 2000b). For this reason in the table 4 there is only one column for recommendations, but we have added different other columns with the minimum and maximum levels known to have been used without trouble and those known to have produced toxicity or deficiency problems.

Table 3 : Recommendations for vitamin supplies in commercial balanced rabbit feeds (LEBAS, 2000b)

Vitamins (units / kg or ppm)	**Advised Supplementation**	Supplementations used without trouble (non purified diets)		Levels known to provoke troubles	
		mini	maxi	deficiency	toxicity
Vitamin A (retinol IU)	**10 000** (1)	6 000	20 000	2 000	100 000
Vitamin D (IU)	**1 000**	600	2 000	300	3 500
Vitamin E (ppm)	**50**	25	10 000	17	(2)
Vitamin K (ppm)	**2**	0	5	0	(2)
Vit. B_1 (thiamine, ppm)	**2** (3)	0	(5)	-	(5)
Vit. B_2 (riboflavin, ppm)	**6** (3)	0	(5)	-	(5)
Niacin (vit. PP, ppm)	**50** (3)	0	(5)	-	(5)
Pantothenic acid (ppm)	**20** (3)	0	(5)	-	(5)
Vit B_6 (pyridoxine, ppm)	**2** (3)	0	(5)	-	(5)
Folic acid (ppm)	**5** (3)	0	(5)		(5)
Vit. B_{12} (ppm)	**0.01** (3)	0	(5)	-	(5)
Biotin (ppm)	**0.10** (3)	0	(5)	-	(5)
Choline (ppm)	**200** (3)	0	(5)	-	(5)
				-	
Vitamin C (ppm)	**250** (4)	0	10 000	-	(2)

(1) may by supplied by 30 ppm of β-carotene. No toxicity of β-carotene
(2) no known toxicity, even with a massive supply (1%)
(3) supplementation advisable in case of risk of digestive trouble (post-weaning, …)
(4) supplementation advisable in situation of stress (heat, …), in a protected form.
(5) no information available on risks of toxicity in relation with a massive supplementation of vitamins of the B-complex, but it is improbable because of the very low capacity of storage of these vitamins in the rabbit organism.

CONCLUSIONS AND PERSPECTIVES

In the past ten years, our knowledge appreciably progressed with respect to nutritional requirements of the weaned rabbit and of reproductive females. Several research programmes now address the improvement of the body reserves of the doe, with 2 major approaches: 1) genetic improvement, in particular for intake capacity ; 2) nutritional preparation of the young doe (from its weaning). On the other hand, little is still known about the digestion and nutritional requirements of the young rabbit before weaning. The nutritional preparation of the young rabbit before its weaning should be improved to reduce the digestive disorders in post-weaning period. Moreover, the relationship between nutrition and digestive pathology of the growing rabbit must be more fully documented. These studies will be useful within the frame of the future legislation for animal feeding that would favour the reduction of drugs such as antibiotics in the production process of any type of meat eaten in the European community..

Likewise, legislation regarding animal breeding will take more and more account of the animal excreta (nitrogen, minerals) and of its negative impact on the environment. Studies on the mineral requirements are presently scarce, and it would be appropriate to develop them. Some studies have already proposed practical solutions to reduce the nitrogen and phosphorus excretion. Moreover, studies of amino acids digestion (contributions to be expressed in digestible form) in the small intestine, will optimise the use of proteins. On this point, work of European group EGRAN aims to standardise and improve methodology of ileal digestibility measurements.

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