Nutritional impact on health and performance in intensively reared rabbits

J. C. De Blas

Departamento de Producción Animal, ETS Ingenieros Agrónomos,

Universidad Politécnica 28040, Madrid, Spain.

E-mail: c.deblas@upm.es

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Abstract

The present work summarizes research related to the definition of nutrient recommendations for feeds used in the intensive production of rabbit's meat. Fibre is the main chemical constituent of rabbit diets that typically contain 320-360 and 50-90 g/kg of insoluble and soluble fibre, respectively. Instead, dietary content of cereal grains (around 120-160 g/kg), fat (15-25 g/kg) and protein concentrates (150-180 g/kg) are usually low with respect to other intensively reared monogastric animals. Cell wall constituents are not well digested in rabbits, but this effect is compensated by its stimulus of gut motility, which leads to an increasing rate of passage of digesta, and allows achieving an elevated DM intake. A high feed consumption and an adequate balance in essential nutrients are required to sustain the elevated needs of high productive rabbits measured either as reproductive yield, milk production or growth rate in the fattening period. Around weaning, pathologies occur in a context of incomplete development of the digestive physiology of young rabbits. The supply of balanced diets has also been related with the prevention of disorders by means of three mechanisms: i) promoting a lower retention time of the digesta in the digestive tract through feeding fibre sources with optimal chemical and physical characteristics, ii) restricting feed intake after weaning or iii) causing a lower flow of easily available substrates into the fermentative area by modifying feed composition (e.g. by lowering protein and starch contents, increasing its digestibility or partially substituting insoluble with soluble fibre), or by delaying age at weaning. The alteration of the gut microbiota composition has been postulated as the possible primary cause of these pathologies.

Keywords: nutrition, feed efficiency, performance, gut health, rabbits.

Introduction

Rabbits are bred all over the world for different purposes. However, its main use as an agricultural species is for intensive meat production, with most of the farms located at the European Mediterranean area. Rabbits present several advantages to provide meat, as a rapid growth rate, short reproductive cycle, high prolificacy, adaptability to farm conditions and ability to thrive on high fibrous ingredients. Moreover, rabbit meat offers excellent nutritive and dietetic properties, as high protein content, low cholesterolaemic effect and low sodium level (Hernandez and Dalle Zotte, 2010). However, consumption is mostly restricted at present to the production areas, with its acceptance being limited by cultural, traditional and religious reasons.

The digestive system of the rabbits is similar to other herbivorous monogastric species, so that digestibility of non cell wall constituents at the small intestine is also comparable. Otherwise, rabbits are characterized by a high relative capacity of the caecum (Postsmouth, 1977), where most of the microbial digestion occurs. Furthermore, rabbits have developed a specific mechanism of particles segregation at the ileocaecal-colonic junction (Björnhag, 1972). This system favours the entrance to the fermentative area of water soluble substances and fine particles (<0.3 mm diameter), whereas coarse particles continue their progression to form the hard faeces. The easily digestive materials entering in the caecum are only retained for a short period of time (about 10 h, Gidenne *et al*., 2010a), as caecal contents are emptied every morning to produce the soft faeces. Consequently, rate of passage of digesta in rabbits is faster than in other herbivorous species (as ruminants or horses), and even than in pigs (Warner, 1981; see Table 1). As a result, rabbits achieve a high voluntary feed intake (approximately four times higher than a 250 kg steer, and twice as much as a 40 kg growing pig on live weight basis; Santomá *et al*., 1989). This high intake capability allows rabbits fed with high fibrous diets to meet their high nutritive requirements per unit of body weight.

Because of caecal mean retention time is relatively short in rabbits, values of NDF digestibility are generally below to those observed in other herbivorous species and also than in pigs (see Table 2). For the same reason, soluble fibre, which is fermented quickly, represents a high proportion of the total cell wall constituents digested (De Blas *et al*., 1999). In fact, most of the fibrolytic activity in rabbits corresponds to pectinases, whereas cellulolytic activity is very scarce (Marounek *et al*., 1995). Other variables as hemicelluloses and ADL concentrations on NDF and the proportion of acid detergent cutin on ADL contribute to explain part of NDF digestibility variations (Escalona *et al*., 1999). Dietary particle size is also a relevant factor of fibre digestion efficiency, since it is significantly related to caecal retention time (García *et al*., 1999).

The digestive system of the rabbits permits the re-utilization of part of the end products of the caecal fermentation (including microorganisms) through the daily ingestion of soft faeces. Caecotrophy allows increasing crude protein digestibility (especially in diets containing a high proportion of NDF insoluble protein) and reducing manure nitrogen excretion. Soft faeces provide as average 0.15 and 0.22, respectively, of the total protein intake in growing rabbits and lactating does (Carabaño *et al*., 2010), with a high concentration of microbial protein (from 0.30 to 0.60), as well of essential amino acids (Nicodemus *et al*., 1999b; García *et al*., 2004). The amount of nutrients recycled depends on factors affecting the efficiency of fibre digestion in the caecum (García *et al*., 1995a; 2000, see Table 3). The stepwise regression equation obtained was:

$\mathrm{MN} = 0.60 + 1.21\ \mathrm{FP} + 3.52\ \mathrm{UA} - 1.20\ \mathrm{ADL/NDF}$

MN = Microbial nitrogen, g/d; FP = Proportion of fine particles (<0.3 mm);
UA = proportion of uronic acids; ADL/NDF = degree of lignification of NDF.

Microbial activity is also responsible for the presence of conjugated linoleic acid in the soft faeces and thus in rabbit's meat, although in smaller amounts than in ruminant species (Gómez-Conde *et al*., 2006). The use of soft faeces has also been proposed for the in vivo estimation of caecal flora composition, including pathogen proliferation (Romero *et al*., 2009b).

Role of fibre in rabbit digestion

Fibrous raw materials are the main constituents of commercial rabbit feeds. Both physical and chemical characteristics of fibre have implications on feed intake, gut health, feed efficiency and performance. Thus, the definition of the optimum dietary levels of fibre has been a major aim of the research on rabbit nutrition.

Rabbit does and fattening rabbits are able to maintain a high DM intake in a range of dietary NDF concentrations (De Blas *et al*., 1986; Méndez *et al*., 1986; Partridge *et al*., 1989; de Blas *et al*., 1995; Gidenne *et al*., 2004). However, a minimal content of lignified, large sized (>0.3 mm) fibre content is needed to ensure a fast rate of passage of digesta (Figure 1) and thus to maximize voluntary feed intake (Figure 2). Results presented in Figure 1 indicate that a concentration of dietary fibre of around 390 g NDF/kg DM is required to minimize digesta accumulation in the caecum (expressed as proportion of caecal content weight on live body weight, %CCW). The stepwise regression equation obtained was:

$$CCW = 19.1(\pm 2.0) - 0.070(\pm 0.011)\ NDF + 0.000089(\pm 0.000015)\ NDF^2 - 0.031(\pm 0.0091)\ ADL/NDF;\ n = 52;\ R^2 = 0.49;\ P < 0.001$$

, the additional negative effect of degree of lignification of NDF (ADL/NDF, %) indicates influence of source of fibre. An increase in the proportion of fine particles (<0.3 mm) and a decrease in the proportion of large particles (>1.25 mm) also increases caecal retention time and decreases DM intake (Gidenne, 1993; García et *al*., 1999).

Accordingly, low fibrous levels lead to a decrease of feed intake and thus of growth performance, whereas fattening mortality increases (see Figure 3). Otherwise, rabbits fed high fibrous diets decrease their digestible energy (DE) intake, weight gain and feed efficiency, as the higher feed consumption observed in these diets does not compensate the sharp decrease of energy digestibility and energy fermentation losses (see Figure 4). A long term study conducted with highly productive rabbit does fed five fibre levels in iso-DE diets, determined that values of reproductive performance, milk production and feed efficiency were maximal for diets containing around 360 g NDF/kg DM (de Blas *et al*., 1995).

Dietary fibre is widely considered as the major nutritional factor to prevent digestive pathologies. The reasons for this relationship are still unclear. Low fibrous diets imply a decrease of substrates available for the fibrolytic flora and a decrease of intestinal peristalsis, which might alter the equilibrium among the microbial species. In this way, a reduction of dietary NDF from 300 to 250 g/kg decreased microbiota diversity at the caecum (Nicodemus *et al*., 2004). Increasing levels of fibre in the diet also lead to a decrease of caecal pH and to an increase of volatile fatty acid concentration (see Figure 5). These changes were greater when highly digestible sources of fibre were used and could contribute to explain the effect of fibre to control pathogen growth (Gidenne *et al*., 2001b; Gidenne and Licois, 2005; Gómez-Conde *et al*., 2007 and 2009). In addition, the partial substitution of insoluble with soluble fibre might minimize the deterioration of intestinal villi caused by highly lignified fibre, and then increase immune response and digestion efficiency, especially in young rabbits (Mourao *et al*., 2006; Alvarez *et al*., 2007; Gómez-Conde *et al*., 2007; Table 4).

Fibre also has a diluting effect on dietary starch content, and avoids an excessive ileal flow of starch that might promote pathogen growth. Starch digestibility is generally very high (>0.97) in rabbits (Blas and Gidenne, 2010).

However, in young rabbits (less than five weeks old), when pancreatic activity is not fully established, ileal starch flow can be significant (Gidenne *et al*., 2005). Starch digestibility also decreases in highly lignified diets (Motta *et al*., 1996; Gómez-Conde *et al*., 2007; see Table 4) or when non-cereal sources (as peas) are used (Gutiérrez *et al*., 2002b). In the same way, the addition of amylases to the diet has proven to be effective in the reduction of fattening mortality in several studies (Gutiérrez *et al*., 2002b; Cachaldora *et al*., 2004).

Recommendations for dietary total fibre levels expressed as NDF, ADF or crude fibre, are shown in Table 5 for the three types of feeds more commonly used in practice. Energy values have been estimated for each average level of fibre and for moderate (45 g/kg) total ether extract content according to De Blas *et al*. (1992). Optimal type of fibre has been considered by proposing minimal levels of soluble NDF and large sized particles. The protective influence of the lignin fraction has also been recognized, because of its favourable effect on digestive disorders observed in several studies (Perez *et al*., 1994; Nicodemus *et al*., 1999a; Gidenne *et al*., 2001a).

Effects of fat addition

Inusion of fats in commercial feeds for rabbits is usually restricted to less than 30-35 g/kg because of its negative influence on pellet and meat quality. However, fat is well digested by rabbits (Maertens *et al*., 1986; Santomá *et al*., 1987) and allows increasing dietary energy concentration and feed conversion rate in typically high fibrous fattening diets (Partridge *et al*., 1996).

Furthermore, several long-term studies indicate that a supplementation with around 30 g/kg of fat in isofibrous diets of highly productive does increased

DE intake, milk production and rate of young rabbit’s survival, especially in high prolific animals (see Table 6). The effects were more evident in multiparous rabbit does. Instead, neither body reserves nor fertility or prolificacy are affected by fat addition according to the review of Fernández-Carmona *et al*., 2000. Recent work (Maertens *et al*., 2005) has also shown that dietary inclusion of linolenic acid might further decrease young rabbit’s mortality and improve reproductive efficiency.

According to the previous information, a minimal addition of 20-30 g/kg of fat is frequently recommended in diets for breeding does, whereas inclusion of fat in fattening feeds depends on its cost per unit of energy.

Recommendations for dietary nitrogen balance

Protein and amino acid requirements for rabbits have been determined in several dose response studies, where both the high growth and milk production potential per unit of live body weight and the recycling of nutrients through caecotrophy are considered. Figure 6 shows the effect of 12 diets that combined factorially three levels of ADF (from 90 to 180 g/kg DM) and four of CP (from 130 to 200 g/kg DM) on the performance of fattening rabbits. Results indicate that a ratio of around 10 g of digestible protein/MJ DE is optimal to reach maximal feed intake, daily weight gain, protein retention and protein efficiency and to minimize fattening mortality. Optimal dietary protein concentrations are higher for lactating does (12 g digestible protein/MJ DE) than for fattening rabbits, as reviewed by Xiccato (1996).

A low amount of protein reaching the caecum has been related to a decrease of the proliferation of total anaerobic bacteria (García-Palomares *et* *al*., 2006), *Clostridium spiroforme* (Haffar *et al*., 1988), *Escherichia coli* (Cortez *et al*., 1992) and *Clostridium perfringens* (Chamorro *et al*., 2007) and to lower incidence of intestinal disorders and fattening mortality according to the works shown in Figure 7. Ileal protein flow in these studies was decreased by lowering dietary protein content, using high digestible sources or supplementing feed with proteolytic enzymes. Otherwise, endogenous nitrogen is another relevant substrate for microbial growth in rabbits (García *et al.*, 2004), but its implication on pathogen proliferation and digestive pathology is still unclear.

Practical recommendations for dietary CP and digestible protein levels, calculated for standard DE values are shown in Table 7. Optimal contents of crude and faecal digestible essential amino acids have been derived from studies reviewed by De Blas and Mateos (2010); an example of one of them is presented in Figure 8.

The full implementation of an accurate system of evaluation of ileal digestibility of amino acids (García *et al*., 2005) would permit increase nitrogen digestion efficiency, and further decrease dietary protein content. Reducing dietary protein concentration at minimal levels also allows decreasing nitrogen excretion through manure (Maertens *et al*., 1997; Xiccato, 2006).

Mineral and vitamin requirements

When compared to other domestic species, rabbit meat is relatively poor in sodium but rich in potassium and phosphorous. Otherwise, rabbits present some particularities as the high content of minerals in milk (Mateos *et al*., 2010). Highly prolific rabbit does producing high amounts of milk can show a deficit of calcium at late gestation or early lactation, with similar symptoms to those of milk fever in dairy cows. An excessive calcium intake is excreted in the urine forming a characteristic precipitate and might damage kidney structure.

Furthermore, rabbits are able to digest partially phytic acid at the caecum and recycle phosphoric acid through soft faeces (Marounek et al., 2003). Accordingly, the digestibility of phytic acid is higher in rabbits than in other monogastric species (Gutiérrez *et al*., 2000). Most of B-vitamins, together to vitamin C and vitamin K are also synthesized by the gut flora and recycled by caecotrophy (Carabaño *et al*., 2010), although dietary supplements might be needed to meet requirements. Other minerals as chloride, sodium and potassium are present in soft faeces in higher concentrations than in hard faeces (Hörnicke and Börnhag, 1980).

There is a lack of research on optimal mineral and vitamin levels for rabbit diet's formulation. Standards proposed in Table 8 are mostly based on practical levels used by the industry.

Feeding management

Weaning is a critical phase for the development of digestive disorders in rabbits, as in other domestic species. Early weaning (at 25 days of age) allows increasing reproductive efficiency in intensively reared rabbits (Méndez *et al*., 1986; Nicodemus *et al*., 2002). However, several works suggest a positive influence of a delay of weaning age (up to 35 days of age) to prevent fattening mortality (Lebas, 1993; Feugier *et al*., 2006; Romero *et al.*, 2009a). This effect might be explained by an insufficient development at early ages of the digestive enzymatic capability (Corring *et al*., 1972; Dojana *et al*., 1998; Scapinello *et al*., 1999; Gutiérrez *et al*., 2002a), which would lead to an increasing flow of nutrients towards the hindgut, and to an alteration of the equilibrium of the gut flora. In this context, late weaning seems to exert a protective effect on the proliferation of *Escherichia coli* O103 (Gallois *et al*., 2007) and *Clostridium perfringens* (Romero *et al*., 2009a). Consequently, in the more typical reproductive rhythm used in commercial practice, rabbit does are mated 11 days after parturition and weaned at 35 days, to get a 42-d length of the reproductive cycle.

Otherwise, a feeding restriction during two weeks after weaning has decreased fattening mortality and improved feed conversion rate in field experiments (Gidenne *et al*., 2009 a, b). These results might be explained by a decrease in caecal pH and a higher caecal concentration of volatile fatty acids (Gidenne and Feugier, 2009), which together to the reduction of the nutrient flow to the hindgut might contribute to reduce pathogen proliferation in the digestive contents of the restricted animals.

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Table 1 *Mean retention time of digesta in the gut of different animal species (adapted from Warner, 1981)*

Species	Mean retention time (h)
Cattle	68.8
Sheep	47.4
Pigs	43.3
Horse	37.9
Rabbit	17.1

Table 2 *Neutral detergent fibre digestibility (NDFd) of several feedstuffs in rabbits*

Feedstuff	NDFd	Reference
Dehydrated lucerne	0.255-0.407	Perez, 1994
Grape seed meal	0.086	García *et al.*, 2002b
Lucerne hay	0.204-0.276	García *et al.*, 1995b
NaOH-treated barley straw	0.094	García *et al.*, 1996
Olive leaves	0.084	García *et al.*, 1996
Soybean hulls	0.306	García *et al.*, 1997
Sunflower hulls	0.107	García *et al.*, 1996

Table 3 *Effect of source of fibre on the recycling of microbial nitrogen through caecotropy (calculated from García et al., 1995a, 2000)*

Feedstuff	Microbial nitrogen, g/d
Paprika meal	0.83
Olive leaves	0.75
Lucerne hay	0.66
Soybean hulls	0.48
NaOH-treated straw	0.34
Sunflower hulls	0.34

Table 4 *Effect of fibre source in diets containing 300 g/kg NDF on the integrity and activity of intestinal barrier, detection frequency of several potential harmful bacteria at caecum, and fattening mortality (Gómez-Conde et al., 2007)*

	Beet-apple pulp	Alfalfa hay	Oat hulls	SEM	P
Villus height (μm)	722^{a}	567^{b}	493^{c}	28.0	0.001
Crypt depth (μm)	89.0^{a}	115^{b}	113^{b}	4.35	0.001
Ileal flow of starch, g/d	0.5^{a}	0.8^{b}	1.2^{c}	0.099	0.001
Lymphocytes CD8+ (%)	21.3	26.9	30.3	2.61	0.074
Frequency of detection at caecum (%)					
Clostridium perfringens	5.7^{a}	2.9^{a}	17.6^{b}	4.2	0.047
Campylobacter spp	19.4	21.2	37.8	6.7	0.074
Fattening mortality (%)	5.3^{a}	8.5^{ab}	14.4^{a}	-	0.05

$^{a,\ b,\ c}$ Values in a row not sharing a common letter differ at P<0.05.

Table 5 *Nutrient requirements of intensively reared rabbits as concentration/kg corrected to a dry matter content 900 g/kg (De Blas and Mateos, 2010)*

Nutrient	Unit	Breeding does	Fattening rabbits	Mixed feed
Digestible energy	MJ	10.7	10.2	10.2
NDF[a]	g	320	340	335
		(310-335)[b]	(330-350)	(320-340)
ADF	g	175	190	180
		(165-185)	(180-200)	(160-180)
Crude fibre	g	145	155	150
		(140-150)	(150-160)	(145-155)
ADL	g	*55*[c]	*50*	*55*
Soluble NDF	g	Free	*115*	*80*
Starch[d]	g	170	150	160

[a] Proportion of long fibre particles (>0.3 mm) should be higher than 0.22 (breeding does) and 0.205 (fattening rabbits).

[b] Values in parentheses indicate range of minimal and maximal values recommended.

[c] Values in italics are provisional estimates.

[d] Values for starch are indicative

Table 6 *Effect of fat addition (35 g/kg pork lard) in lactating rabbit diets on intake and performance (Fraga et al., 1989)*

	Control	Fat added	SEM	P
Food intake per lactation (1-28 d)				
Dry matter, kg	8.03	9.01	0.27	NS
Digestible energy	91.5	117	3.71	<0.001
Milk yield (kg)	4.70	5.68	0.26	0.05
Prolificacy	9.19	8.90	0.57	NS
Litter weight at 21 days (kg)	2.30	2.72	0.13	0.05
Survival rate at 21 days				
All litters	0.81	0.91	-	NS
Litters n>9	0.75	0.90	-	0.05

Table 7 *Protein and amino acid requirements of intensively reared rabbits as concentration/kg corrected to a dry matter content of 900g/kg (De Blas and Mateos, 2010)*

Nutrient	Unit	Breeding does	Fattening rabbits	Mixed feed
Digestible energy	MJ	10.7	10.2	10.2
Crude protein[a]	g	175	150	159
		(165-185)	(142-160)	(154-162)
Digestible protein[b]	g	128	104	111
		(115-140)	(100-110)	(108-113)
Lysine[c]				
Total	g	8.1	7.3	7.8
Digestible	g	6.4	5.7	6.1
Sulphur[d]				
Total	g	6.3	5.2	5.9
Digestible	g	4.8	4.0	4.5
Threonine[e]				
Total	g	6.7	6.2	6.5
Digestible	g	4.6	4.3	4.5

[a] Values in parentheses indicate range of minimal and maximal values recommended.

[b] Digestibility of crude protein and essential amino acids is expressed as faecal apparent digestibility

[c] Total amino acid requirements have been calculated for a contribution of synthetic amino acids of 0.15.

[d] Methionine should provide a minimum of 35% of the total TSAA requirements.

[e] Maximal levels of 50 and 72 g/kg of digestible and total threonine, respectively, are recommended for breeding does.

Table 8 *Mineral and vitamin acid requirements of intensively reared rabbits as concentration/kg corrected to a dry matter content of 900g/kg (De Blas and Mateos, 2010)*

Nutrient	Unit	Breeding does	Fattening rabbits	Mixed feed
Calcium	g	10.5	6	100
Phosphorus	g	6	4	57
Sodium	g	2.3	2.2	22
Chloride	g	2.9	2.8	28
Cobalt	mg	0.3	0.3	0.3
Copper	mg	10	6	10
Iron	mg	50	30	45
Iodine	mg	1.1	0.4	1.0
Manganese	mg	15	8	12
Selenium	mg	0.05	0.05	0.05
Zinc	mg	60	35	60
Vitamin A	mIU	10	6	10
Vitamin D	mIU	0.9	0.9	0.9
Vitamin E	IU	50	15	40
Vitamin K_3	mg	2	1	2
Vitamin B_1	mg	1	0.8	1
Vitamin B_2	mg	5	3	5
Vitamin B_6	mg	1.5	0.5	1.5
Vitamin B_{12}	µg	12	9	12

Folic acid	mg	1.5	0.1	1.5
Niacin	mg	35	35	35
Pantothenic acid	mg	15	8	15
Biotin	µg	100	10	100
Choline	mg	200	100	200

Figure 1 Influence of dietary NDF content on the weight of caecal contents (García *et al*., 2002a).

Figure 2 Effect of weight of caecal contents on DM intake at two experimental sites: UPM and INRA (García *et al*., 2002a).

Figure 3 Effect of dietary NDF content on growth performance and feed conversion rate (FCR, g/g) of fattening rabbits in two independent studies (—●— de Blas *et al.,* 1986; -✳- Gidenne *et al.,* 2004).

Figure 4 Influence of dietary ADF content on energy digestibility (ED, De Blas *et al*., 1992) and efficiency of digestible energy for energy retention in growth (RE/DEi; De Blas *et al*., 1985; Ortiz *et al*., 1988; García *et al*., 1992, 1993).

Figure 5 Effect of dietary NDF content on caecal pH and caecal volatile fatty acids concentration in studies carried out at different laboratories (García *et al*., 2002a).

Figure 6 Influence of the dietary digestible protein (DP) to digestible energy (DE) ratio on DM intake, average daily gain (ADG, g) and mortality in the fattening period (De Blas *et al*., 1981), the fat and protein content in the empty body weight (%; Fraga *et al*., 1983) and the efficiency of retention of digestible protein intake (RP/DPi, De Blas *et al*., 1985).

Figure 7 Effect of the apparent ileal flow of protein at the post-weaning period on the fattening mortality according to several experiments.

Figure 8 Effect of dietary apparent faecal digestible threonine concentration (g/kg DM) on productive traits of lactating does (Base 100 = diet containing 3.44 g digestible threonine/kg; De Blas et al., 1998).