Nutritional impact on health and performance in intensively reared rabbits

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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 to 360 and 50 to 90 g/kg of insoluble and soluble fibre, respectively. Instead, the dietary contents of cereal grains (120 to 160 g/kg), fat (15 to 25 g/kg) and protein concentrates (150 to 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 dry matter 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 to 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 in the gut microbiota composition has been postulated as the possible primary cause of these pathologies.

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

Implications

The present work summarizes research related to the definition of nutrient recommendations for feeds used in the intensive production of rabbit's meat.

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 in the European Mediterranean area. Rabbits present several advantages to provide meat, such as a rapid growth rate, a 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, such as a high protein content, low cholesterol-olaenic effect and low sodium level (Hernández and Dalle Zotte, 2010). However, consumption is mostly restricted at present to the production areas, with its acceptance being limited due to 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 (Portsmouth, 1977), where most of the microbial digestion occurs. Furthermore, rabbits have a specific mechanism of particle segregation at the ileocaecal–colonic junction (Björnhaag, 1972). This system favours the entry into the fermentative area of water-soluble substances and fine particles (<0.3 mm diameter), whereas coarse particles continue their progression to form hard faeces. The easily digestive materials entering the caecum are only retained for a short period of time (~10 h; Gidenne et al., 2010a), as caecal contents are emptied every morning to produce soft faeces. Consequently, the rate of passage of digesta in rabbits is faster than that in other herbivorous species (such as ruminants or horses) and even pigs (Warner, 1981; see Table 1). As a result, rabbits achieve a high voluntary feed intake (~four times higher than a 250 kg...
steer, and twice as much as a 40 kg growing pig on a 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 BW.

Because the caecal mean retention time is relatively short in rabbits, values of NDF digestibility are generally lower than those observed in other herbivorous species and also 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 such as hemicelluloses and ADL concentrations on NDF and the proportion of acid detergent cutin on ADL may be partially responsible for the variations in NDF digestibility (Escalona et al., 1999). Dietary particle size is also a relevant factor of fibre digestion efficiency, as 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 caecal fermentation (including microorganisms) through the daily ingestion of soft faeces. Caecotrophy allows increasing CP digestibility (including microorganisms) through the daily ingestion of soft faeces. Caecotrophy allows increasing CP digestibility 

<table>
<thead>
<tr>
<th>Feedstuff</th>
<th>NDFd</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dehydrated lucerne</td>
<td>0.255 to 0.407</td>
<td>Perez (1994)</td>
</tr>
<tr>
<td>Grape seed meal</td>
<td>0.086</td>
<td>García et al. (2002b)</td>
</tr>
<tr>
<td>Lucerne hay</td>
<td>0.204 to 0.276</td>
<td>García et al. (1995b)</td>
</tr>
<tr>
<td>NaOH-treated barley straw</td>
<td>0.094</td>
<td>García et al. (1996)</td>
</tr>
<tr>
<td>Olive leaves</td>
<td>0.084</td>
<td>García et al. (1996)</td>
</tr>
<tr>
<td>Soya bean hulls</td>
<td>0.306</td>
<td>García et al. (1997)</td>
</tr>
<tr>
<td>Sunflower hulls</td>
<td>0.107</td>
<td>García et al. (1996)</td>
</tr>
</tbody>
</table>

Table 2: NDFd of several feedstuffs in rabbits

NDFd — neutral detergent fibre digestibility.

The amount of nutrients recycled depends on factors affecting the efficiency of fibre digestion in the caecum (García et al., 1995a and 2000; see Table 3). The stepwise regression equation obtained was

\[
MN = 0.60 + 1.21FP + 3.52UA - 1.20ADL / NDF
\]

where MN is the microbial nitrogen (g/day); FP the proportion of fine particles (<0.3 mm); UA the proportion of uronic acids; and ADL/NDF the 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 for feed intake, gut health, feed efficiency and performance. Thus, the definition of the optimum dietary levels of fibre has been a major aim of research on rabbit nutrition.

Rabbit does and fattening rabbits are able to maintain a high dry matter (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 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). The results presented in Figure 1 indicate that a concentration of dietary fibre of ~390 g NDF/kg DM is required to minimize digesta accumulation in the caecum (expressed as the proportion of caecal content weight (CCW) on live BW, %CCW). The stepwise regression equation obtained was

\[
CCW = 19.1 (±2.0) − 0.070 (±0.011) NDF + 0.000089 (±0.000015) NDF^2 − 0.031 (±0.0091) ADL / NDF;
\]

\[n = 52; R^2 = 0.49; P < 0.001\]

The additional negative effect of the degree of lignification of NDF (ADL/NDF, %) indicates the influence of the source of fibre. An increase in the proportion of fine particles
and a decrease in the proportion of large particles (>1.25 mm) also increase caecal retention time and decrease DM intake (Gidenne, 1993; García et al., 1999). Accordingly, low fibrous levels lead to a decrease in feed intake and thus in 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 for the sharp decrease in energy digestibility and energy fermentation losses (see Figure 4). A long-term study conducted with highly productive rabbit does fed five fibre levels

\[ \text{Figure 1} \quad \text{Influence of dietary NDF content on the weight of caecal contents (García et al., 2002a).} \]

\[ \text{Figure 2} \quad \text{Effect of weight of caecal contents on dry matter intake at two experimental sites: UPM and INRA (García et al., 2002a). CCW = caecal content weight; LWG = live weight gain.} \]

\[ \text{Figure 3} \quad \text{Effect of dietary NDF content on growth performance and feed conversion rate (FCR, g/g) of fattening rabbits in two independent studies (de Blas et al., 1986; Gidenne et al., 2004).} \]
in iso-DE diets showed that values of reproductive performance, milk production and feed efficiency were maximal for diets containing \( \sim 360 \) 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 are still unclear. Low fibrous diets imply a decrease in substrates available for the fibrolytic flora and a decrease in 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 in caecal pH and to an increase in volatile fatty acid concentration (see Figure 5). These changes were greater when highly

![Figure 4](image-url)  
**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., 1989; García et al., 1992, 1993).

![Figure 5](image-url)  
**Figure 5** Effect of dietary NDF content on caecal pH and caecal volatile fatty acid concentration in studies carried out at different laboratories (García et al., 2002a).
digestible sources of fibre were used and may explain the role of fibre in controlling 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; 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 5 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 been proven to be effective in the reduction of fattening mortality in primarily high fibrous fattening diets (Partridge et al., 1986). Starch digestibility decreases in highly lignified diets (Partridge et al., 1986) and allows increasing the dietary energy concentration and the feed conversion rate in typically high fibrous fattening diets (Partridge et al., 1986).

**Effects of fat addition**

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

**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)

<table>
<thead>
<tr>
<th>Nutrient Unit</th>
<th>Breeding does</th>
<th>Fattening rabbits</th>
<th>Mixed feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestible energy (MJ)</td>
<td>10.7</td>
<td>10.2</td>
<td>10.2</td>
</tr>
<tr>
<td>NDF (g)</td>
<td>320</td>
<td>340</td>
<td>335</td>
</tr>
<tr>
<td>ADF (g)</td>
<td>175</td>
<td>190</td>
<td>180</td>
</tr>
<tr>
<td>Crude fibre (g)</td>
<td>145</td>
<td>155</td>
<td>150</td>
</tr>
<tr>
<td>ADL (g)</td>
<td>55</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Soluble NDF (g)</td>
<td>Free</td>
<td>175</td>
<td>80</td>
</tr>
<tr>
<td>Starch (g)</td>
<td>170</td>
<td>150</td>
<td>160</td>
</tr>
</tbody>
</table>

*a,b,cValues 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)

<table>
<thead>
<tr>
<th>Nutrient Unit</th>
<th>Breeding does</th>
<th>Fattening rabbits</th>
<th>Mixed feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (kg)</td>
<td>8.03</td>
<td>9.01</td>
<td>0.27</td>
</tr>
<tr>
<td>Digestible energy (MJ)</td>
<td>91.5</td>
<td>117</td>
<td>3.71</td>
</tr>
<tr>
<td>Milk yield (kg)</td>
<td>4.70</td>
<td>5.68</td>
<td>0.26</td>
</tr>
<tr>
<td>Litter weight at 21 days (kg)</td>
<td>2.30</td>
<td>2.72</td>
<td>0.13</td>
</tr>
<tr>
<td>All litters</td>
<td>0.81</td>
<td>0.91</td>
<td>–</td>
</tr>
<tr>
<td>Litters (n &gt; 9)</td>
<td>0.75</td>
<td>0.90</td>
<td>–</td>
</tr>
</tbody>
</table>

Furthermore, several long-term studies have shown that a supplementation with ~30 g/kg of fat in isofibrous diets of highly productive does increased DE intake, milk production and rate of young rabbits’ survival, especially in high prolific animals (see Table 6). The effects were more evident in multiparous rabbit does. Instead, neither body reserves nor

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

<table>
<thead>
<tr>
<th>Food intake per lactation (1 to 28 days)</th>
<th>Control</th>
<th>Fat added</th>
<th>SEM</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (kg)</td>
<td>8.03</td>
<td>9.01</td>
<td>0.27</td>
<td>ns</td>
</tr>
<tr>
<td>Digestible energy (MJ)</td>
<td>91.5</td>
<td>117</td>
<td>3.71</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Milk yield (kg)</td>
<td>4.70</td>
<td>5.68</td>
<td>0.26</td>
<td>0.05</td>
</tr>
<tr>
<td>Litter weight at 21 days (kg)</td>
<td>2.30</td>
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</tr>
<tr>
<td>All litters</td>
<td>0.81</td>
<td>0.91</td>
<td>–</td>
<td>ns</td>
</tr>
<tr>
<td>Litters (n &gt; 9)</td>
<td>0.75</td>
<td>0.90</td>
<td>–</td>
<td>0.05</td>
</tr>
</tbody>
</table>

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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 rabbits’ mortality and improve reproductive efficiency.

According to the previous information, a minimal addition of 20 to 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 BW and the recycling of nutrients through caecotrophy have been 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 ~10 g of digestible protein/MJ DE is optimal to achieve 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 (DP)/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 in 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 incidences of intestinal disorders and fattening mortality according to the works shown in Figure 7. Ileal protein flow in these studies was decreased by lowering the 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 role in pathogen proliferation and digestive pathology is still unclear.

Practical recommendations for dietary CP and DP levels, calculated for standard DE values, are shown in Table 7.

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**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 BW (%; Fraga et al., 1983) and the efficiency of retention of DP intake (RP/DPi; De Blas et al., 1985).
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 an increase in nitrogen digestion efficiency and a further decrease in dietary protein content. Reducing dietary protein concentration to minimal levels also allows decreasing nitrogen excretion through manure (Maertens et al., 1997; Xiccato, 2006).

Mineral and vitamin requirements

When compared with other domestic species, rabbit meat is relatively poor in sodium but rich in potassium and phosporous. Otherwise, rabbits present some particularities such 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 symptoms similar to those of milk fever in dairy cows. An excessive calcium intake is excreted in the urine, forming a characteristic precipitate, and might damage the kidney structure.

Furthermore, rabbits are able to partially digest 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 B-vitamins, together with vitamin C and vitamin K, are also synthesized by the gut flora and recycled by caecotrophy (Caraballo et al., 2010), although dietary supplements might be needed to meet the requirements. Other minerals such as chloride, sodium and potassium are present in soft faeces in higher concentrations than in hard faeces (Hörnicke and Björnhag, 1980).

There is a lack of research on optimal mineral and vitamin levels for rabbits’ diet formulation. The 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 in the equilibrium of the gut flora. In this context, late weaning seems to exert a protective effect on the proliferation of E. coli O103 (Gallois et al., 2007) and C. perfringens (Romero et al., 2009a). Consequently, in the more typical reproductive rhythm used in

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### 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)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Unit</th>
<th>Breeding does</th>
<th>Fattening rabbits</th>
<th>Mixed feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestible energy MJ</td>
<td>10.7</td>
<td>10.2</td>
<td>10.2</td>
<td></td>
</tr>
<tr>
<td>CP&lt;sup&gt;a&lt;/sup&gt; g</td>
<td>175</td>
<td>150</td>
<td>159</td>
<td>(165 to 185)</td>
</tr>
<tr>
<td>Digestible protein&lt;sup&gt;b&lt;/sup&gt; g</td>
<td>128</td>
<td>104</td>
<td>111</td>
<td>(115 to 140)</td>
</tr>
<tr>
<td>Lysine&lt;sup&gt;c&lt;/sup&gt; Total g</td>
<td>8.1</td>
<td>7.3</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>Digestible g</td>
<td>6.4</td>
<td>5.7</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>Sulphur&lt;sup&gt;d&lt;/sup&gt; Total g</td>
<td>6.3</td>
<td>5.2</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>Digestible g</td>
<td>4.8</td>
<td>4.0</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Threonine&lt;sup&gt;e&lt;/sup&gt; Total g</td>
<td>6.7</td>
<td>6.2</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>Digestible g</td>
<td>4.6</td>
<td>4.3</td>
<td>4.5</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Values in parentheses indicate range of minimal and maximal values recommended.  
<sup>b</sup>Digestibility of CP and essential amino acids is expressed as faecal apparent digestibility.  
<sup>c</sup>Total amino acid requirements have been calculated for a contribution of synthetic amino acids of 0.15.  
<sup>d</sup>Methionine should provide a minimum of 35% of the total total sulphur amino acid requirements.  
<sup>e</sup>Maximal levels of 50 and 72 g/kg of digestible and total threonine, respectively, are recommended for breeding does.
commercial practice, rabbit does are mated 11 days after parturition and weaned at 35 days to achieve a 42-day length of the reproductive cycle.

Otherwise, a feeding restriction during 2 weeks after weaning has decreased fattening mortality and improved the feed conversion rate in field experiments (Gidenne et al., 2009a and 2009b). 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 with the reduction of the nutrient flow to the hindgut, might contribute towards reducing pathogen proliferation in the digestive contents of the restricted animals.

References


Nutrition, performance and health of rabbits


