

1 **Nutritional impact on health and performance in intensively reared rabbits**

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8 Running head. Nutrition, performance and health of rabbits

9
10 **Abstract**

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

13 Fibre is the main chemical constituent of rabbit diets that typically contain 320-
14 360 and 50-90 g/kg of insoluble and soluble fibre, respectively. Instead, dietary
15 content of cereal grains (around 120-160 g/kg), fat (15-25 g/kg) and protein
16 concentrates (150-180 g/kg) are usually low with respect to other intensively
17 reared monogastric animals. Cell wall constituents are not well digested in
18 rabbits, but this effect is compensated by its stimulus of gut motility, which leads
19 to an increasing rate of passage of digesta, and allows achieving an elevated
20 DM intake. A high feed consumption and an adequate balance in essential
21 nutrients are required to sustain the elevated needs of high productive rabbits
22 measured either as reproductive yield, milk production or growth rate in the
23 fattening period. Around weaning, pathologies occur in a context of incomplete
24 development of the digestive physiology of young rabbits. The supply of
25 balanced diets has also been related with the prevention of disorders by means

26 of three mechanisms: i) promoting a lower retention time of the digesta in the
27 digestive tract through feeding fibre sources with optimal chemical and physical
28 characteristics, ii) restricting feed intake after weaning or iii) causing a lower
29 flow of easily available substrates into the fermentative area by modifying feed
30 composition (e.g. by lowering protein and starch contents, increasing its
31 digestibility or partially substituting insoluble with soluble fibre), or by delaying
32 age at weaning. The alteration of the gut microbiota composition has been
33 postulated as the possible primary cause of these pathologies.

34

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

36

37 **Introduction**

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

48 The digestive system of the rabbits is similar to other herbivorous
49 monogastric species, so that digestibility of non cell wall constituents at the
50 small intestine is also comparable. Otherwise, rabbits are characterized by a

51 high relative capacity of the caecum (Postsmouth, 1977), where most of the
52 microbial digestion occurs. Furthermore, rabbits have developed a specific
53 mechanism of particles segregation at the ileocaecal-colonic junction (Björnhag,
54 1972). This system favours the entrance to the fermentative area of water
55 soluble substances and fine particles (<0.3 mm diameter), whereas coarse
56 particles continue their progression to form the hard faeces. The easily digestive
57 materials entering in the caecum are only retained for a short period of time
58 (about 10 h, Gidenne *et al.*, 2010a), as caecal contents are emptied every
59 morning to produce the soft faeces. Consequently, rate of passage of digesta in
60 rabbits is faster than in other herbivorous species (as ruminants or horses), and
61 even than in pigs (Warner, 1981; see Table 1). As a result, rabbits achieve a
62 high voluntary feed intake (approximately four times higher than a 250 kg steer,
63 and twice as much as a 40 kg growing pig on live weight basis; Santomá *et al.*,
64 1989). This high intake capability allows rabbits fed with high fibrous diets to
65 meet their high nutritive requirements per unit of body weight.

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

76 digestion efficiency, since it is significantly related to caecal retention time
77 (García *et al.*, 1999).

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

$$90 \text{ MN} = 0.60 + 1.21 \text{ FP} + 3.52 \text{ UA} - 1.20 \text{ ADL/NDF}$$

91 MN = Microbial nitrogen, g/d; FP = Proportion of fine particles (<0.3 mm);

92 UA = proportion of uronic acids; ADL/NDF = degree of lignification of NDF.

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

98

99 **Role of fibre in rabbit digestion**

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

105 Rabbit does and fattening rabbits are able to maintain a high DM intake
106 in a range of dietary NDF concentrations (De Blas *et al.*, 1986; Méndez *et al.*,
107 1986; Partridge *et al.*, 1989; de Blas *et al.*, 1995; Gidenne *et al.*, 2004).
108 However, a minimal content of lignified, large sized (>0.3 mm) fibre content is
109 needed to ensure a fast rate of passage of digesta (Figure 1) and thus to
110 maximize voluntary feed intake (Figure 2). Results presented in Figure 1
111 indicate that a concentration of dietary fibre of around 390 g NDF/kg DM is
112 required to minimize digesta accumulation in the caecum (expressed as
113 proportion of caecal content weight on live body weight, %CCW). The stepwise
114 regression equation obtained was:

$$115 \text{ CCW} = 19.1(\pm 2.0) - 0.070(\pm 0.011) \text{ NDF} + 0.000089(\pm 0.000015) \text{ NDF}^2 - \\ 116 0.031(\pm 0.0091) \text{ ADL/NDF}; n = 52; R^2 = 0.49; P < 0.001$$

117 , the additional negative effect of degree of lignification of NDF (ADL/NDF, %)
118 indicates influence of source of fibre. An increase in the proportion of fine
119 particles (<0.3 mm) and a decrease in the proportion of large particles (>1.25
120 mm) also increases caecal retention time and decreases DM intake (Gidenne,
121 1993; García *et al.*, 1999).

122 Accordingly, low fibrous levels lead to a decrease of feed intake and thus
123 of growth performance, whereas fattening mortality increases (see Figure 3).
124 Otherwise, rabbits fed high fibrous diets decrease their digestible energy (DE)

125 intake, weight gain and feed efficiency, as the higher feed consumption
126 observed in these diets does not compensate the sharp decrease of energy
127 digestibility and energy fermentation losses (see Figure 4). A long term study
128 conducted with highly productive rabbit does fed five fibre levels in iso-DE diets,
129 determined that values of reproductive performance, milk production and feed
130 efficiency were maximal for diets containing around 360 g NDF/kg DM (de Blas
131 *et al.*, 1995).

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

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

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

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

166

167 **Effects of fat addition**

168 Inclusion of fats in commercial feeds for rabbits is usually restricted to less than
169 30-35 g/kg because of its negative influence on pellet and meat quality.
170 However, fat is well digested by rabbits (Maertens *et al.*, 1986; Santomá *et al.*,
171 1987) and allows increasing dietary energy concentration and feed conversion
172 rate in typically high fibrous fattening diets (Partridge *et al.*, 1996).

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

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

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

185

186 **Recommendations for dietary nitrogen balance**

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

198 A low amount of protein reaching the caecum has been related to a
199 decrease of the proliferation of total anaerobic bacteria (García-Palomares *et*

200 *al.*, 2006), *Clostridium spiroforme* (Haffar *et al.*, 1988), *Escherichia coli* (Cortez
201 *et al.*, 1992) and *Clostridium perfringens* (Chamorro *et al.*, 2007) and to lower
202 incidence of intestinal disorders and fattening mortality according to the works
203 shown in Figure 7. Ileal protein flow in these studies was decreased by lowering
204 dietary protein content, using high digestible sources or supplementing feed
205 with proteolytic enzymes. Otherwise, endogenous nitrogen is another relevant
206 substrate for microbial growth in rabbits (García *et al.*, 2004), but its implication
207 on pathogen proliferation and digestive pathology is still unclear.

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

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

218

219 **Mineral and vitamin requirements**

220 When compared to other domestic species, rabbit meat is relatively poor in
221 sodium but rich in potassium and phosphorous. Otherwise, rabbits present
222 some particularities as the high content of minerals in milk (Mateos *et al.*, 2010).
223 Highly prolific rabbit does producing high amounts of milk can show a deficit of
224 calcium at late gestation or early lactation, with similar symptoms to those of

225 milk fever in dairy cows. An excessive calcium intake is excreted in the urine
226 forming a characteristic precipitate and might damage kidney structure.

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

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

239

240 **Feeding management**

241 Weaning is a critical phase for the development of digestive disorders in rabbits,
242 as in other domestic species. Early weaning (at 25 days of age) allows
243 increasing reproductive efficiency in intensively reared rabbits (Méndez *et al.*,
244 1986; Nicodemus *et al.*, 2002). However, several works suggest a positive
245 influence of a delay of weaning age (up to 35 days of age) to prevent fattening
246 mortality (Lebas, 1993; Feugier *et al.*, 2006; Romero *et al.*, 2009a). This effect
247 might be explained by an insufficient development at early ages of the digestive
248 enzymatic capability (Corring *et al.*, 1972; Dojana *et al.*, 1998; Scapinello *et al.*,
249 1999; Gutiérrez *et al.*, 2002a), which would lead to an increasing flow of

250 nutrients towards the hindgut, and to an alteration of the equilibrium of the gut
251 flora. In this context, late weaning seems to exert a protective effect on the
252 proliferation of *Escherichia coli* O103 (Gallois *et al.*, 2007) and *Clostridium*
253 *perfringens* (Romero *et al.*, 2009a). Consequently, in the more typical
254 reproductive rhythm used in commercial practice, rabbit does are mated 11
255 days after parturition and weaned at 35 days, to get a 42-d length of the
256 reproductive cycle.

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

264

265 **References**

266 Alvarez JL, Marguenda I, García-Rebollar P, Carabaño R, De Blas JC, Corujo A and
267 García-Ruiz AI 2007. Effects of type and level of fibre on digestive physiology and
268 performance in reproducing and growing rabbits. *World Rabbit Science* 15, 9-17.

269

270 Björnhag G 1972. Separation and delay contents in the rabbit colon. *Swedish Journal*
271 *of Agricultural Research* 2, 125-136.

272

273 Blas E and Gidenne T 2010. Digestion of sugars and starch. In *The nutrition of the*
274 *rabbit* (2nd ed) (ed. JC de Blas and J Wiseman), pp. 19-38. CABI Publishing CAB
275 International, Wallingford, UK.

276

277 Cachaldora P, Nicodemus N, García J, Carabaño R and De Blas JC 2004. Efficacy of
278 amylofeed in growing rabbit diets. *World Rabbit Science* 12, 23-31.

279

280 Carabaño R, Piquer J, Menoyo D and Badiola I 2010. The digestive system of the
281 rabbit. In *The nutrition of the rabbit* (2nd ed) (ed. JC de Blas and J Wiseman), pp. 1-18.
282 CABI Publishing CAB International, Wallingford, UK.

283

284 Chamorro S, Gómez-Conde MS, Pérez de Rozas AM, Badiola I, Carabaño R and De
285 Blas JC 2007. Effect on digestion and performance of dietary protein content and of
286 increased substitution of lucerne hay with soya-bean protein concentrate in starter diets
287 for young rabbits. *Animal* 1, 651-659.
288

289 Corring T, Lebas F and Cortout D 1972. Contrôle de l'évolution de l'équipement
290 enzymatique du pancréas exocrine de la naissance à 6 semaines. *Annales de Biologie*
291 *Animale, Biochimie et Biophysique* 12, 221-231.
292

293 Cortez S, Brandebruger H, Greuel E and Sundrum A 1992. Investigations of the
294 relationships between feed and health-status on the intestinal flora of rabbits.
295 *Tierärztliche Umschau* 47, 544-549.
296

297 De Blas JC and Mateos GG 2010. Feed formulation. In *The nutrition of the rabbit* (2nd
298 ed) (ed. JC de Blas and J Wiseman), pp. 222-232. CABI Publishing CAB International,
299 Wallingford, UK.
300

301 De Blas JC, Pérez E, Fraga MJ, Rodríguez M and Gálvez J 1981. Effect of diet on feed
302 intake and growth of rabbits from weaning to slaughter at different ages and weights.
303 *Journal of Animal Science* 52, 1225-1232.
304

305 De Blas JC, Fraga MJ and Rodríguez JM 1985. Units for feed evaluation and
306 requirements for commercially grown rabbits. *Journal of Animal Science* 60, 1021-
307 1028.
308

309 De Blas JC, Santomá G, Carabaño R and Fraga MJ 1986. Fiber and starch levels in
310 fattening rabbit diets. *Journal of Animal Science* 63, 1897-1904.
311

312 De Blas JC, Wiseman J, Fraga MJ and Villamide MJ 1992. Prediction of the digestible
313 energy and digestibility of gross energy of feeds for rabbits. 2. Mixed diets. *Animal Feed*
314 *Science and Technology* 39, 39-59.
315

316 De Blas JC, Taboada E, Mateos GG, Nicodemus N and Méndez J 1995. Effect of
317 substitution of starch for fiber and fat in isoenergetic diets on nutrient digestibility and
318 reproductive performance of rabbits. *Journal of Animal Science* 73, 1131-1137.
319

320 De Blas JC, Taboada E, Nicodemus N, Campos R, Piquer J and Méndez J 1998.
321 Performance response of lactating and growing rabbits to dietary threonine content.
322 *Animal Feed Science and Technology* 70, 151-160.
323

324 De Blas JC, García J and Carabaño R 1999. Role of fibre in rabbit diets. A review.
325 *Annales Zootechnie*. 48, 3-13.
326

327 Dojana N, Costache M and Dinischiotu A 1998. The activity of some digestive enzymes
328 in domestic rabbits before and after weaning. *Animal Science* 66, 501-507.
329

330 Escalona B, Rocha R, García J, Carabaño R and de Blas JC 1999. Characterization of
331 in situ fibre digestion of several fibrous foods. *Animal Science* 68, 217-221.
332

333 Fernández-Carmona J, Pascual JJ and Cervera C 2000. The use of fat in rabbit diets.
334 World Rabbit Science 8 (suppl. 1), 29-59.
335

336 Feugier A, Smit MN, Fortun-Lamothe L and Gidenne T 2006. Fibre and protein
337 requirements of early weaned rabbits and the interaction with weaning age: effects on
338 digestive health and growth performance. Animal Science 82, 493-500.
339

340 Fraga MJ, de Blas C, Pérez E, Rodríguez JM, Pérez C and Gálvez J 1983. Effects of
341 diet on chemical composition of rabbits slaughtered at fixed body weights. Journal of
342 Animal Science 56, 1097-1104.
343

344 Fraga MJ, Lorente M, Carabaño R and de Blas C 1989. Effect of diet and of remating
345 interval on milk production and milk composition of the doe rabbit. Animal Production
346 48, 459-466.
347

348 Gallois M, Gidenne T, Tasca C, Caubet C, Coudert C, Milon A and Boullier S 2007.
349 Maternal milk contains antimicrobial factors that protect young rabbits from
350 enteropathogenic Escherichia coli infection. Clinical Vaccine Immunology 14, 585-592.
351

352 García AI, De Blas JC and Carabaño R 2004. Effect of type of diet (casein-based or
353 protein-free) and caecotrophy on ileal endogenous nitrogen and amino acid flow in
354 rabbits. Animal Science 79, 231-240.
355

356 García AI, De Blas JC and Carabaño R 2005. Comparison of different methods for
357 nitrogen and amino acid evaluation in rabbit diets. Animal Science 80, 169-178.
358

359 García G, Gálvez JF and De Blas JC 1992. Substitution of barley grain by sugar-beet
360 pulp in diets for finishing rabbits. 2. Effect on growth performance. Journal of Applied
361 Rabbit Research 15, 1017-1024.
362

363 García G, Gálvez JF and De Blas JC 1993. Effect of substitution of sugarbeet pulp for
364 barley in diets for finishing rabbits on growth performance and on energy and nitrogen
365 efficiency. Journal of Animal Science 71, 1823-1830.
366

367 García J, De Blas JC, Carabaño R and Garcia P 1995a. Effect of type of lucerne hay
368 on cecal fermentation and nitrogen contribution through caecotrophy in rabbits.
369 Reproduction Nutrition Development 35, 267-275.
370

371 Garcia J, Perez-Alba L, Alvarez C, Rocha R, Ramos M and De Blas JC 1995b.
372 Prediction of the nutritive value of lucerne hay in diets for growing rabbits. Animal Feed
373 Science and Technology 54, 33-44.
374

375 García J, Villamide MJ and De Blas JC 1996. Energy, protein and fibre digestibility of
376 sunflower hulls, olive leaves and NaOH-treated barley Straw for rabbits. World Rabbit
377 Science 4, 205-209.
378

379 García J, Villamide MJ and De Blas JC 1997. Energy, protein and fibre digestibility of
380 soya bean hulls for rabbits. World Rabbit Science 5, 111-113.
381

382 García J, Carabaño R and De Blas JC 1999. Effect of fiber source on cell wall
383 digestibility and rate of passage in rabbits. *Journal of Animal Science* 77, 898-905.
384

385 García J, Carabaño R, Perez Alba L and De Blas JC 2000. Effect of fiber source on
386 cecal fermentation and nitrogen recycled through cecotrophy in rabbits. *Journal of*
387 *Animal Science* 78, 638-646.
388

389 García J, Gidenne T, Falcao L and De Blas JC 2002a. Identification of the main factors
390 that influence cecal fermentation traits in growing rabbits. *Animal Research* 51, 165-
391 173.
392

393 García J, Nicodemus N, Carabaño R and De Blas JC 2002b. Effect of inclusion of
394 defatted grape seed meal in the diet on digestion and performance of growing rabbits.
395 *Journal of Animal Science* 80, 162-170.
396

397 García-Palomares J, Carabaño R, García-Rebollar P, De Blas JC, Corujo A and
398 García-Ruiz AI 2006. Effects of a dietary protein reduction and enzyme
399 supplementation on growth performance in the fattening period. *World Rabbit*
400 *Science* 14, 231-236.
401

402 García-Ruiz AI, García-Palomares J, García-Rebollar P, Chamorro S, Carabaño R and
403 De Blas JC 2006. Effect of protein source and enzyme supplementation on ileal protein
404 digestibility and fattening performance in rabbits. *Spanish Journal of Agricultural*
405 *Research* 4, 297-303.
406

407 Gidenne T 1993. Measurement of the rate of passage in restricted-fed rabbits: effect of
408 dietary cell wall level on the transit of fibre particles of different sizes. *Animal Feed*
409 *Science and Technology* 42, 151-163.
410

411 Gidenne T and Licois D 2005. Effect of high fibre intake on the resistance of the
412 growing rabbit to an experimental inoculation with an enteropathogenic strain of
413 *Escherichia coli*. *Animal Science* 80, 281-288.
414

415 Gidenne T and Feugier A 2009. Feed restriction strategy in the growing rabbit. 1.
416 Impact on digestion, rate of passage and microbial activity. *Animal* 3, 501-508.
417

418 Gidenne T, Arveux P and Madec O 2001a. The effect of the quality of dietary
419 lignocellulose on digestion, zootechnical performance and health of the growing rabbit.
420 *Animal Science* 73, 97-104.
421

422 Gidenne T, Kerdiles V, Jehl N, Arveux P, Briens C, Eckenfelder B, Fortune H,
423 Montessuy S, Muraz, G and Stephan S 2001b. In An increase of dietary ratio digestible
424 fibre/crude protein does not affect the performances of the growing rabbit but reduce
425 enteritis incidence: preliminary results of a multi-site study (ed. G Bolet), pp. 65-68.
426 *Proceedings 9th J. Rech. Cunicoles, Paris, France. ITAVI publ. Paris.*
427

428 Gidenne T, Jehl N, Lapanouse A and Segura M 2004. Inter-relationship of microbial
429 activity, digestion and gut health in the rabbit: effect of substituting fibre by starch in
430 diets having a high proportion of rapidly fermentable polysaccharides. *British Journal of*
431 *Nutrition* 92, 95-104.

432

433 Gidenne T, Segura M and Lapanouse A 2005. Effect of cereal sources and processing
434 in diets for the growing rabbit. I. Effects on digestion and fermentative activity in the
435 caecum. *Animal Research* 54, 55-64.

436

437 Gidenne T, Combes S, Feugier A, Jehl N, Arveux P, Boisot P, Briens C, Corrent E,
438 Fortune H, Montessuy S and Verdelhan S 2009a. Feed restriction strategy in the
439 growing rabbit. 2. Impact on digestive health, growth and carcass characteristics.
440 *Animal* 3, 509-515.

441

442 Gidenne T, Murr S, Travel A, Corrent E, Foubert C, Bebin K, Mevel L, Rebours G and
443 Renouf B 2009b. Effets du niveau de rationnement et du mode de distribution de
444 l'aliment sur les performances et les troubles digestifs post-sevrage du lapereau.
445 *Cuniculture* 36, 65-72.

446

447 Gidenne T, Carabaño R, García J and De Blas JC 2010a. Fibre digestion. In *The*
448 *nutrition of the rabbit* (2nd ed) (ed. JC de Blas and J Wiseman), pp. 66-82. CABI
449 Publishing CAB International, Wallingford, UK.

450

451 Gidenne T, García J, Lebas F and Licois D 2010b. Nutrition and feeding strategy:
452 Interactions with pathology. In *The nutrition of the rabbit* (2nd ed) (ed. JC de Blas and J
453 Wiseman), pp. 179-199. CABI Publishing CAB International, Wallingford, UK.

454

455 Gómez-Conde MS, Menoyo D, Chamorro S, López-Bote CJ, García-Rebollar P and De
456 Blas JC 2006. Conjugated linoleic acid content in cecotrophes, suprarenal and
457 intramuscular fat in rabbits fed commercial diets. *World Rabbit Science* 14, 95-99.

458

459 Gómez-Conde MS, García J, Chamorro S, Eiras P, Rebollar PG, Pérez de Rozas A,
460 Badiola I, de Blas JC and Carabaño R 2007. Neutral detergent-soluble fiber improves
461 gut barrier function in 25 d old weaned rabbits. *Journal of Animal Science* 85, 3313-
462 3321.

463

464 Gómez-Conde MS, Pérez de Rozas A, Badiola I, Pérez-Alba L, De Blas JC, Carabaño
465 R and García J 2009. Effect of neutral detergent soluble fibre on digestion, intestinal
466 microbiota and performance in twenty five day old weaned rabbits. *Livestock Science*,
467 125, 192-198.

468

469 Gutiérrez I, García J, Carabaño R, Mateos GG and De Blas JC 2000. Effect of
470 exogenous phytase on phosphorus and nitrogen digestibility in growing-finishing
471 rabbits. *World Rabbit Science* 8 (suppl. 1), 277-281.

472

473 Gutiérrez I, Espinosa A, García J, Carabaño R and De Blas JC 2002a. Effect of levels
474 of starch, fiber and lactose on digestion and growth performance of early-weaned
475 rabbits. *Journal of Animal Science* 80, 1029-1037.

476

477 Gutiérrez I, Espinosa A, García J, Carabaño R and De Blas JC 2002b. Effects of starch
478 and protein sources, heat processing and exogenous enzymes in starter diets for
479 early weaned rabbits. *Animal Feed Science and Technology* 98, 175-186.

480

481 Gutierrez I, Espinosa A, Garcia J, Carabaño R and De Blas JC 2003. Effect of source
482 of protein on digestion and growth performance of early-weaned rabbits. *Animal*
483 *Research* 52, 461-472.
484
485 Haffar A, Laval A and Guillou JP 1988. Entérotoxémie à *Clostridium* spiroforme chez
486 des lapins adultes. *Le Point Vétérinaire* 20, 99-102.
487
488 Hernández P and Dalle Zotte A 2010. Influence of diet on rabbit meat quality. In *The*
489 *nutrition of the rabbit* (2nd ed) (ed. JC de Blas and J Wiseman), pp. 163-178. CABI
490 Publishing CAB International, Wallingford, UK.
491
492 Hörnicke H and Björnhag G 1980. Coprophagy and related strategies for digesta
493 utilization. In *Digestive Physiology and Metabolism in Ruminants* (ed. Y Ruckebusch
494 and P Thivend), pp. 707-730. MTP Press, Lancaster, UK.
495
496 Lebas F 1993. Amélioration de la viabilité des lapereux en engraissement par un
497 sevrage tardif. *Cuniculture* 20, 73-75.
498
499 Maertens L, Huyghebaert G and De Groote G 1986. Digestibility and digestible energy
500 content of various fats for growing rabbits. *Cuni-Science* 3, 7-14.
501
502 Maertens L, Luzi F and De Groote G 1997. Effect of dietary protein and amino acids on
503 the performance, carcass composition and N excretion of growing rabbits *Annales de*
504 *Zootecnie* 46, 255-268.
505
506 Maertens L, Aerts JM and De Brabander DL 2005. Effect of a diet rich in n-3 fatty acids
507 on the performances and milk composition of does and the viability of their progeny. In
508 *Proceedings of the 11èmes Journées de la Recherche Cunicole*, Paris, pp. 209-212.
509
510 Marounek M, Vovk SJ and Skrivanova V 1995. Distribution of hydrolytic enzymes in
511 the digestive tract of rabbits. *British Journal of Nutrition* 73, 463-469.
512
513 Marounek M, Duskova D and Skrivanova V 2003. Hydrolysis of phytic acid and its
514 availability in rabbits. *British Journal of Nutrition* 89, 287-294.
515
516 Mateos GG, Rebollar PG and De Blas JC 2010. Minerals, vitamins and additives. In
517 *The nutrition of the rabbit* (2nd ed) (ed. JC de Blas and J Wiseman), pp. 119-150. CABI
518 Publishing CAB International, Wallingford, UK.
519
520 Méndez J, De Blas JC and Fraga MJ 1986. The effects of diet and remating interval
521 after parturition on the reproductive performance of the commercial doe rabbit *Journal*
522 *of Animal Science* 86, 1624-1634.
523
524 Motta W, Fraga MJ and Carabaño R 1996 Inclusion of grape pomace in substitution for
525 alfalfa hay, in diets for growing rabbits. *Animal Science* 63, 167-174.
526
527 Mourao JL, Pinheiro V, Alves A, Guedes CM, Pinto L, Saavedra MJ, Spring P and
528 Kocher A 2006. Effect of mannan oligosaccharides on the performance, intestinal
529 morphology and cecal fermentation in rabbits. *Animal Feed Science and Technology*
530 126, 107-120.

531
532 Nicodemus N, Carabaño R, García J, Méndez J and De Blas JC 1999a. Performance
533 response of lactating and growing rabbits to dietary lignin content. *Animal Feed*
534 *Science and Technology* 80, 43-54.
535
536 Nicodemus N, Mateos J, De Blas JC, Carabaño R and Fraga MJ 1999b. Effect of diet
537 on amino acid composition of soft faeces and the contribution of soft faeces to total
538 amino acid intake, through caecotrophy in lactating doe rabbits. *Animal Science* 69,
539 167-170.
540
541 Nicodemus N, Gutiérrez I., García J, Carabaño R and De Blas C 2002. The effect of
542 remating interval and weaning age on the reproductive performance of rabbit does.
543 *Animal Research* 51, 517-523.
544
545 Nicodemus N, Pérez-Alba L, Carabaño R, De Blas JC, Badiola I, Pérez de Rozas A and
546 García J 2004. Effect of level of fibre and level of ground of fibre sources on digestion
547 and ileal and caecal characterization of microbiota of early weaned rabbits. In 8th World
548 Rabbit Congress. Puebla, México, pp 143 (Abstract).
549
550 Ortiz V, De Blas JC and Sanz E 1989. Effect of dietary fiber and fat content on energy
551 balance in fattening rabbits. *Journal of Applied Rabbit Research* 12, 159-162.
552
553 Partridge GG, Findlay M and Fordyce RA 1986. Fat supplementation of diets for
554 growing rabbits. *Animal Feed Science and Technology* 16, 109-117.
555
556 Partridge GG, Garthwaite PH and Findlay M 1989. Protein and energy retention by
557 growing rabbits offered diets with increasing proportions of fibre. *Journal of Agricultural*
558 *Science* 112, 171-178.
559
560 Perez JM 1994. Digestibilité et valeur énergetique des luzernes deshydratées pour le
561 lapin: influence de leur composition chimique et de leur technologie de preparation. In
562 Vièmes Journées de la Recherche Cunicole, La Rochelle, Vol 2, pp. 355-364.
563
564 Perez JM, Gidenne T, Lebas F, Caudron Y, Arveux P, Boudillon A, Duperray J and
565 Messenger B. 1994. Apports de lignines et alimentation du lapin en croissance. 2.
566 Conséquences sur les performances et la mortalité. *Annales Zootechnie* 43, 323-332.
567
568 Portsmouth JI 1977. The nutrition of the rabbits. In: *Nutrition and the Climatic*
569 *Environment* (ed. W Haresign, H Swan and D Lewis), pp. 93-111. Butterworths,
570 London, UK.
571
572 Romero C, Nicodemus N, García-Rebollar P, García-Ruiz AI, Ibáñez MA and de Blas
573 JC, 2009a. Dietary level of fibre and age at weaning affect the proliferation of
574 *Clostridium perfringens* in the caecum, the incidence of Epizootic Rabbit Enteropathy
575 and the performance of fattening rabbits. *Animal Feed Science and Technology* 153,
576 131-140.
577
578 Romero C, Nicodemus N, García-Ruiz AI, Ibáñez MA and de Blas JC 2009b. The use
579 of soft faeces for the prediction of the caecal contents concentration of *Clostridium*

580 perfringens in relation with epizootic rabbit enteropathy. Spanish Journal of Agricultural
581 Research 7, 807-812.
582
583 Santomá G, De Blas JC, Carabaño R and Fraga MJ 1987. The effects of different fats
584 and their inclusion level in diets for growing rabbits. Animal Production 45, 291-300.
585
586 Santomá G, De Blas JC, Carabaño R and Fraga MJ 1989. Nutrition of rabbits. In
587 Recent Advances in Animal Nutrition (ed. W. Haresign and DJA Cole), pp. 109-138.
588 Butterworths, London.
589
590 Scapinello C, Gidenne T and Fortun-Lamothe L 1999. Digestive capacity of the rabbit
591 during the post-weaning period, according to the milk/solid feed intake pattern before
592 weaning. Reproduction Nutrition Development 39, 423-432.
593
594 Warner A 1981. Rate of passage of digesta through the gut of mammals and birds.
595 Nutrition Abstract and Review 51, 789-820.
596
597 Xiccato G 1996 Nutrition of lactating does. In Proceedings of the 6th World Rabbit
598 Congress. Association Française de Cuniculture (ed. F Lebas), pp. 175-180. Lempdes.
599
600 Xiccato G 2006. Nutrition of the young and growing rabbit: a comparative approach
601 with the doe. In Recent Advances in Rabbit Sciences (ed. L Maertens and P Coudert),
602 pp 239-246. Ilvo, Merelbeke, Belgium.
603

604

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

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

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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 <i>et al.</i> , 2002b
Lucerne hay	0.204-0.276	García <i>et al.</i> , 1995b
NaOH-treated barley straw	0.094	García <i>et al.</i> , 1996
Olive leaves	0.084	García <i>et al.</i> , 1996
Soybean hulls	0.306	García <i>et al.</i> , 1997
Sunflower hulls	0.107	García <i>et al.</i> , 1996

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613 **Table 3** *Effect of source of fibre on the recycling of microbial nitrogen through*

614 *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

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617 **Table 4** *Effect of fibre source in diets containing 300 g/kg NDF on the integrity and*
 618 *activity of intestinal barrier, detection frequency of several potential harmful bacteria at*
 619 *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 (%)					
<i>Clostridium perfringens</i>	5.7 ^a	2.9 ^a	17.6 ^b	4.2	0.047
<i>Campylobacter</i> spp	19.4	21.2	37.8	6.7	0.074
Fattening mortality (%)	5.3 ^a	8.5 ^{ab}	14.4 ^a	-	0.05

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

621

622 **Table 5** *Nutrient requirements of intensively reared rabbits as concentration/kg*
623 *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 (310-335) ^b	340 (330-350)	335 (320-340)
ADF	g	175 (165-185)	190 (180-200)	180 (160-180)
Crude fibre	g	145 (140-150)	155 (150-160)	150 (145-155)
ADL	g	55 ^c	50	55
Soluble NDF	g	Free	115	80
Starch ^d	g	170	150	160

624 ^aProportion of long fibre particles (>0.3 mm) should be higher than 0.22 (breeding
625 does) and 0.205 (fattening rabbits).

626 ^bValues in parentheses indicate range of minimal and maximal values recommended.

627 ^cValues in italics are provisional estimates.

628 ^dValues for starch are indicative

629

630 **Table 6** *Effect of fat addition (35 g/kg pork lard) in lactating rabbit diets on intake and*
 631 *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

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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)

Nutrient	Unit	Breeding does	Fattening rabbits	Mixed feed
Digestible energy	MJ	10.7	10.2	10.2
Crude protein ^a	g	175 (165-185)	150 (142-160)	159 (154-162)
Digestible protein ^b	g	128 (115-140)	104 (100-110)	111 (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

638 ^aValues in parentheses indicate range of minimal and maximal values recommended.
639 ^bDigestibility of crude protein and essential amino acids is expressed as faecal
640 apparent digestibility
641 ^cTotal amino acid requirements have been calculated for a contribution of synthetic
642 amino acids of 0.15.
643 ^dMethionine should provide a minimum of 35% of the total TSAA requirements.
644 ^eMaximal levels of 50 and 72 g/kg of digestible and total threonine, respectively, are
645 recommended for breeding does.

647 **Table 8** *Mineral and vitamin acid requirements of intensively reared rabbits as*
 648 *concentration/kg corrected to a dry matter content of 900g/kg (De Blas and Mateos,*
 649 *2010)*

Nutrient	Unit	Breeding	Fattening	Mixed feed
		does	rabbits	
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

651
652 **Figure 1** Influence of dietary NDF content on the weight of caecal contents (García *et*
653 *al.*, 2002a).

654
655 **Figure 2** Effect of weight of caecal contents on DM intake at two experimental sites:
656 UPM and INRA (García *et al.*, 2002a).

657
658 **Figure 3** Effect of dietary NDF content on growth performance and feed conversion
659 rate (FCR, g/g) of fattening rabbits in two independent studies (—●— de Blas *et al.*,
660 1986; - * - Gidenne *et al.*, 2004).

661
662 **Figure 4** Influence of dietary ADF content on energy digestibility (ED, De Blas *et al.*,
663 1992) and efficiency of digestible energy for energy retention in growth (RE/DEi; De
664 Blas *et al.*, 1985; Ortiz *et al.*, 1988; García *et al.*, 1992, 1993).

665
666 **Figure 5** Effect of dietary NDF content on caecal pH and caecal volatile fatty acids
667 concentration in studies carried out at different laboratories (García *et al.*, 2002a).

668
669 **Figure 6** Influence of the dietary digestible protein (DP) to digestible energy (DE) ratio
670 on DM intake, average daily gain (ADG, g) and mortality in the fattening period (De
671 Blas *et al.*, 1981), the fat and protein content in the empty body weight (%; Fraga *et al.*,
672 1983) and the efficiency of retention of digestible protein intake (RP/DPI, De Blas *et al.*,
673 1985).

674
675 **Figure 7** Effect of the apparent ileal flow of protein at the post-weaning period on the
676 fattening mortality according to several experiments.

677

678 **Figure 8** Effect of dietary apparent faecal digestible threonine concentration (g/kg DM)
679 on productive traits of lactating does (Base 100 = diet containing 3.44 g digestible
680 threonine/kg; De Blas et al., 1998).
681