



HAL
open science

Onset of feed intake of the suckling rabbit and evidence of dietary preferences according to pellet physical properties

Charlotte Paes, Laurence Fortun-Lamothe, K. Bébin, J. Duperray, C. Gohier, E. Guené-Grand, G. Rebours, Patrick Aymard, Carole Bannelier, Anne-Marie Debrusse, et al.

► To cite this version:

Charlotte Paes, Laurence Fortun-Lamothe, K. Bébin, J. Duperray, C. Gohier, et al.. Onset of feed intake of the suckling rabbit and evidence of dietary preferences according to pellet physical properties. *Animal Feed Science and Technology*, 2019, 255, Non paginé. 10.1016/j.anifeedsci.2019.114223 . hal-02288154

HAL Id: hal-02288154

<https://hal.science/hal-02288154>

Submitted on 20 Jul 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 Onset of feed intake of the suckling rabbit and evidence of dietary preferences according to
2 pellet physical properties

3

4

5 C. Paës^{ab}, L. Fortun-Lamothe^a, K. Bebin^b, J. Duperray^c, C. Gohier^d, E. Guené-Grand^e, G. Rebours^f, P.
6 Aymard^g, C. Bannelier^a, A.-M. Debrusse^g, T. Gidenne^a, S. Combes^{a*}

7

8

9

10

11 ^a*GenPhySE, Université de Toulouse, INRA, ENVT, Toulouse INP, 31326 Castanet Tolosan, France*

12 ^b*CCPA, ZA du Bois de Teillay, 35150 Janzé, France*

13 ^c*EVIALIS, Lieu dit Talhouët, 56250 Saint Nolff, France*

14 ^d*MiXscience, 2 avenue de Ker Lann, 35170 Bruz, France*

15 ^e*INZO, Rue de l'église, BP50019, 02407 Chierry, France*

16 ^f*TECHNA, Route de St-Étienne-de-Montluc, 44220 Couëron, France*

17 ^g*INRA, UE1322 PECTOUL, 24 chemin de Borde-Rouge, 31326 Castanet-Tolosan, France*

18

19 * Corresponding author: Tel: +33 (0)5 61 28 51 06;

20 EM: sylvie.combes@inra.fr

21

22

23

24

25 **Abstract**

26 Weaning represents a critical period for rabbit, with a high susceptibility to gastrointestinal
27 diseases. Stimulating early solid feed intake **could** contribute to preserving health in rabbit.
28 Thus, the aims of this study were, first, to quantify early solid intake and, second, to
29 determine young rabbit pellet preferences according to their physical properties. Double-
30 choice tests of pellets processed with different dies were conducted in two trials. An original
31 feeding system was used to specifically measure consumption of suckling rabbits in the nest
32 independent of that of the does. Pellets were provided from 3 to **17** days in the nest box and
33 intake was measured daily. From 15 to 35 days, kits received pellets in feeders and intake was
34 measured every 4 days. In the first trial, four pellet diameters were tested in pairs against each
35 other: (A) 2.0, (B) 3.0, (C) 4.0 and (D) 6.0 mm. In the second trial, pellets of identical
36 diameter (2.5 or 4.0 mm) were manufactured with three die channel lengths: (E) 10, (F) 12,
37 (G) 14 mm or (C) 18, (H) 20 and (I) 24 mm. For a given diameter, pellets were tested in pairs.
38 This resulted in six combinations per trial (n = 10 litters per combination). Solid feed intake
39 began at 8 days for 89 out of 118 litters. Over the first 17 days of life, a rabbit ingested a total
40 of 1.63 ± 0.76 g of **dry matter** in the nest in addition to milk. The solid feed intake at 2 weeks
41 of age was correlated with litter weight at the beginning of the experiment ($r = 0.50$ between
42 15 and 17 days; $P < 0.05$). In the feeders, rabbits selected pellet A (61%, 67% and 86% of
43 relative consumption when compared with B, C and D). In the second trial, pellet I was
44 slightly disliked compared to C when provided in the nest ($P < 0.05$), and compared to H in the
45 feeders ($P < 0.05$). It was concluded that suckling rabbits were able to ingest solid feed in the
46 nest box and to discriminate pellets according to their presentation when a choice was given.
47 Providing young rabbits with an easy-access feeding system and an optimal pellet
48 presentation may help to stimulate early solid intake and thus pave the way for further studies
49 on nutritional control of microbiota implantation.

50 *Keywords:* Rabbit; Weaning; Solid consumption; Pellet die; Feed preference

51 *Abbreviations:* ADFom, acid detergent fiber expressed exclusive of residual ash; aNDFom,
52 neutral detergent fiber assayed with a heat stable amylase and expressed exclusive of residual
53 ash; DM, dry matter; Lignin (sa), lignin determined by solubilization of cellulose with
54 sulphuric acid; RC, relative consumption; SC, swelling capacity; SEM, standard error of the
55 mean; WHC, water holding capacity

56 **1. Introduction**

57 Despite consequent improvements in rabbit feed formulation and husbandry practices
58 since the 1980s, a high incidence of digestive disorders around the time of weaning can still
59 be observed. In this context, antibiotic use remains high on meat rabbit farms (Méheust et al.,
60 2017). The cost of antimicrobials and the spread of antibiotic-resistant bacteria have increased
61 the need for alternatives to antibiotic use.

62 Establishing a stable digestive microbiota at an early stage could enhance rabbit
63 resilience to the stress of weaning (Fortun-Lamothe and Boullier, 2007; Combes et al., 2013).
64 Indeed, relationships between enteric infection and disruption of the normal microbiota
65 (known as dysbiosis) have been highlighted in different species such as rabbit (Sekirov and
66 Finlay, 2009; Bäuerl et al., 2014). As in the case of human children and piglets (Konstantinov
67 et al., 2004; Koenig et al., 2011), the rabbit kit digestive microbiota composition is strongly
68 shaped by solid feed intake (Padilha et al., 1995, 1999). Previous studies demonstrated that
69 ingestion by kits of doe feces left in the nest can speed up colonization of microbial cecum
70 (Kovács et al., 2006; Combes et al., 2014). Solid intake via ingestion of fecal pellets or feed
71 offered in the nest can start 2-3 days after birth (Gidenne et al., 2013; Combes et al., 2014;
72 Kacsala et al., 2017). As opposed to fecal pellet ingestion, neonatal solid feed intake behavior
73 has never been quantified.

74 Since newborn rabbits are able to ingest solid feed, and since this behavior can
75 contribute to triggering the installation of microbiota, we hypothesize that providing palatable
76 feed to the kits is an opportunity to strengthen rabbit gut health. However, in rabbit farming,
77 kits only have access to pelleted feed when they start leaving the nest box at around 16-18
78 days (Gidenne and Fortun-Lamothe, 2002). Moreover, no data exists to validate the ability of
79 the physical properties of the common industrial pellet to encourage early feed intake.
80 Preliminary studies investigated the effect of pellet hardness on rabbit intake in rabbits from
81 2- to 5-weeks old, but this effect could have been combined with feed composition or pellet
82 size effect (Gidenne et al., 2007; Travel et al., 2009). Maertens (1994) previously showed that
83 pellet size had an effect on rabbit intake after weaning, with higher consumption when a large
84 pellet diameter (4.8 mm) was offered, suggesting that the physical properties of feed are key
85 factors to optimize solid feed intake.

86 The aims of this study were (i) to quantify kit feed intake from 8 to 35 d, and (ii) to
87 determine the optimal pellet diameter and hardness necessary to stimulate the onset of feed
88 intake. To reach these goals, an original feeding system in the nest was designed and nine
89 pellets with different press die specifications (i.e., length and diameter) were offered in
90 double-choice tests before weaning to evaluate kit feed preferences and intake.

91

92 **2. Material and methods**

93 The study was conducted by the Groupe d'Experimentation Cunicole (GEC) network¹
94 and the experiments were carried out at the PECTOUL Experimental Unit (INRA, Castanet-

1 GEC is a French network of companies with expertise on rabbit production and nutrition. It includes CCPA, EVIALIS, INZO, MiXscience and TECHNA.

95 Tolosan, France). Animals were handled according to the recommendations for animal care in
96 experimentation in agreement with the EU Directive 2010/63/EU (Anonymous, 2010) and
97 the Journal Officiel de la République Française (Anonymous, 2013).

98 2.1. Animal management and housing

99 Female rabbits (hybrid breed PS19; Hypharm, France) were inseminated with semen
100 from male commercial breeds for two successive reproductive cycles (first two lactations).
101 The does and their litter (n = 60 and 63 for the first and second trial, respectively) were raised
102 together in a ventilated breeding unit in individual wire cages (width: 61 x length: 69 x height:
103 61 cm). Cages were equipped to allow the mother and its litter to be fed separately. In that
104 respect, a wire mesh partition separated the doe from the area containing the kits' feeders. The
105 doe's feeder in the cage was elevated so that the kits could not access to the doe's feed (Fig.
106 1). Two days after parturition (day 2), nest quality was assessed using a 3-point scale: 1
107 represented a nest of weak quality in which only wood shavings were found; 2 represented a
108 nest of medium quality in which doe fur was present but insufficient to fully cover the litter;
109 and 3 corresponded to a nest of good quality in which doe fur entirely covered the litter. After
110 nest quality assessment, the litter size was standardized to ten kits per doe by cross-fostering
111 or culling. The doe could access to the nest once a day for suckling (controlled suckling
112 between 8:00 and 9:00 am for 10 min) until day 21. After day 21, the doe could freely access
113 to the nest. Two water nipples were available: one in the doe area and one in the litter space.
114 Feed was offered *ad libitum* to the youngs in the nest (width: 25 x length: 38 x height: 20 cm)
115 from 3 to 17 days of age using two plastic cups (volume: 30 mL; Ø = 40 mm; height: 32 mm;
116 GOSSELIN®, Le Mans, France), placed opposite the doe's entrance (Fig. 2). The feed present
117 in the nest was removed before suckling to prevent the doe from eating it, then weighed and
118 finally reintroduced after suckling. Cups were carefully maintained in holders (6-cm high) and
119 contained feed pellets that differed by their physical characteristics alone (same formulation).

120 From 15 to 35 d, the same kind of pellets **was** offered *ad libitum* outside the nest in the litter
121 area using two feeders, one for each type of pellet tested. The kits' feeders were designed as
122 presented by Fortun-Lamothe et al. (2000), with triangular-shaped openings to limit waste. To
123 avoid confusion between feed placement and pellet preference, the location of cups or feeders
124 containing each pellet type was reversed when feeding measurements were performed. The
125 feeding scheme is summarized in Fig. 3. Milk production was measured as the difference of
126 female weight before and after suckling at 3 or 4, 7, 10, 14, 17 and 21 **days**. Litter weight after
127 suckling was recorded at 3 or 4, 10, 14, 21, 28 **days**.

128 At weaning (35 **days of age**), kits were assigned to cages of five rabbits/cage (width:
129 78 x length: 46 x height: 30 cm) according to the double-choice preference test conducted and
130 litter of origin. Individual rabbit weight was measured at weaning, at 50 and 64 **days of age**.
131 Following common feeding strategy in France, the animals were given restricted feed until 64
132 **days** in order to achieve an average daily gain of 40 g/day. Animals were then fed freely until
133 slaughter (**day 72**). Rabbit mortality was recorded daily from 3 to 72 **days of age**.

134 2.2. Diet processing

135 Does were fed a commercial feed (without any antibiotics) adapted to the lactation
136 stage (Table 1). The diet for suckling rabbit was formulated to meet the nutrient needs of both
137 does and kits. The feed mash was manufactured by Euronutrition SAS (Saint-Symphorien,
138 France). Nine kinds of pellets from different dies were then produced (Tecaliman, Nantes,
139 France) from the same mash to ensure that pellets had identical chemical composition. The
140 ingredients and chemical composition of the pelleted feeds are presented in Table 1. In the
141 pelletizer, the meal was delivered to a conditioning chamber where the quantity and pressure
142 of added steam were controlled to ensure that the mash was at 65°C before flowing into the
143 mill die chamber. To process the pellets, the mash was forced through one of the nine dies
144 with a specific channel length and diameter (Table 2). Die length-to-diameter ratio (also

145 referred to as compression rate) is known to influence hardness (Thomas and Van der Poel,
146 1996). Therefore, die size was the parameter chosen to obtain the desired pellets: pellets with
147 four different diameters and similar hardness in Trial 1 (A, B, C, D), and pellets with three
148 different hardnesses for two given diameters in Trial 2 (E, F, G and C, H, I).

149 *2.3 Experimental design*

150 From 3 to 35 **days**, to assess solid feed preferences, each litter was offered two pellet
151 types while they were still suckling the doe. A complete double-choice feeding protocol was
152 performed in both trials. In the first trial, four pellets were tested in pairs, which resulted in
153 six combinations (AB, AC, AD, BC, BD, and CD, where comparison treatment AB
154 represented pellet A tested against pellet B, etc.). In this trial for diameter preference, we had
155 run out of pellet A stock at 32 **days**, thus ending the preference trial. Hardness preference was
156 assayed in Trial 2, comparing 2.5-mm-diameter pellets against each other and 4.0-mm-
157 diameter pellets against each other. These comparisons of pellets with the same diameter but
158 with different compression rates resulted in six comparison treatments (EF, EG, FG and CH,
159 CI, HI). Pellet C was used in both trials. The litters were assigned to one double-choice
160 treatment according to doe parity (only primiparous in Trial 1 and a parity rank of 1.9 ± 0.01
161 in Trial 2) and to kit weight (average **body weight** at 2 **days** was 66 ± 1 g per kit in Trial 1 and
162 72 ± 1 g per kit in Trial 2). Allocation inside the farm was also equally divided between the
163 treatments. Each treatment had ten or eleven litters of ten rabbits at the beginning of the
164 experiment.

165 *2.4 Evaluation of the feed intake*

166 Early feed intake was calculated daily based on the weight of feed offered and refused
167 from 3 to 17 **days of age** in the first trial using a 0.001-g accuracy scale (OHAUS, Parsippany,
168 NJ, USA). Water loss, measured as the difference of pellet weight between two days in the
169 absence of animals, was measured the first days of the experiment for the four pellets A, B, C

170 and D. After correction for these intrinsic changes, it was found that feed intake was
171 negligible the first week. For this reason, feed intake was measured daily from 8 to 17 days in
172 the second trial. When waste or cup spillage occurred, we considered feed consumption in the
173 two cups as missing data. In these cases, all of the nest material was renewed to ensure that no
174 pellets were left inside the nest. Remaining feed in the feeders was weighed at 18, 21, 25, 28,
175 32 and 35 days of age. If one kit was found dead between these dates, the remaining feed in
176 the cage was weighed to recalculate feed intake.

177 *2.5 Physical characteristics of pellets*

178 Pellet length and diameter were measured with a caliper with a resolution of 0.5 mm
179 (ROCH, France). Diameters obtained were in accordance with the die used during the pellet
180 processing (Table 3), with the biggest pellet (pellet D) 3-fold larger than the smallest one
181 (pellet A). Pellet hardness was determined with the Kahl Pellet Hardness Tester (AMANDUS
182 KAHL GmbH & Co. KG, Reinbek, Germany) on a minimum of ten pellets. Each pellet was
183 inserted between two bars with an increasing static pressure to determine the force needed to
184 crack it (Thomas and Van der Poel, 1996). Force values obtained in Newtons were then
185 expressed as a pressure variable to take account of the length and diameter of each pellet
186 tested as follows:

$$187 \quad H = Hm / (\pi * l * r)$$

188 where H is the calculated hardness (MPa), Hm is the measured hardness (N), l is the length of
189 the pellet (mm), and r is the pellet radius (mm)

190 Pellet durability is “the amount of fines returning from pellets after they were
191 subjected to an abrading action” (Thomas and Van der Poel, 1996). For each measurement,
192 200 g of feed pellets were tumbled in a SABE drum (SABE Distribution, Chauche, France) at
193 500 rpm for 20 seconds. After tumbling, the fines (particles of less than 2 mm) were removed.

194 Durability was expressed as the percentage of remaining pellets (ISO 17831-1:2015). This
195 procedure was repeated three times per pellet type.

196 The particle size distribution was determined after water and ultrasonic treatments
197 according to the Lebas and Lamboley procedure (1999). Water-holding capacity (WHC) and
198 feed-swelling capacity (SC) were measured for each type of pellet to check for confusing
199 effects since these properties affect satiation (Tan et al., 2017). WHC was determined twice
200 according to the Giger Reverdin (2000) method: 2 g of sample were poured into 10 mL
201 distilled water and left to soak for 24 hours, so that water was in excess. After centrifugation,
202 wet supernatant was removed and weighed to measure water absorption. WHC was calculated
203 as the ratio of the supernatant weight to the sample dry matter weight. SC was obtained by
204 dissolving 2 g of sample in 25 mL distilled water. After 1 hour at room temperature, the
205 increased volume of the feedstuff due to hydration was measured to determine SC, as
206 previously described by (Arroyo et al., 2012). WHC and SC were measured in triplicate.

207 *2.6. Chemical analysis of the feeds*

208 Chemical analysis was performed on the nine experimental pre-weaning pellets and on
209 the commercial pellets provided to the does using the ISO methods and the procedures
210 described by the European Group on Rabbit Nutrition (EGRAN, 2001). Dry matter (DM) was
211 obtained after 24 h at 103°C (ISO 6496:1999) and ashes after 5 h at 550°C. Total nitrogen
212 was determined with the DUMAS combustion method using an automatic analyzer (Vario El
213 cube model; Elementar, Langenselbold, Germany) to approximate the crude protein content
214 ($N \times 6.25$) (ISO 16634-1:2008). Neutral detergent fiber (aNDFom) and acid detergent fiber
215 (ADFom) were measured using the sequential method of Van Soest et al. (1991) with a heat-
216 stable amylase pre-treatment (AFNOR, 1997). Results were expressed exclusive of residual
217 ash. Lignin analyses were performed on ADFom residues by solubilization of cellulose with
218 sulfuric acid (sa). Starch was determined with the enzymatic procedure described by

219 Kozłowski (1994): starch was solubilized in potassium hydroxide and then hydrolyzed with
220 amyloglucosidase. Released glucose molecules were finally quantified with the hexokinase
221 glucose 6-phosphate dehydrogenase system (D-Glucose®; Boehringer, Mannheim,
222 Germany). Intense ether washing was performed using the Tecator Soxtec system HT (FOSS,
223 Hilleroed, Denmark - acid hydrolysis pre-treatment) to determine crude fat content (ISO
224 6492:1999). Gross energy was established with adiabatic combustion (Model C5000 adiabatic
225 calorimeter; IKA, Staufen, Germany) (ISO 9831:1998).

226 2.7. Calculation and statistical analysis

227 Before weaning, statistical models include the litter as the experimental unit, whereas
228 after weaning, the individual animal is the experimental unit. Feed intake values in the nest
229 (8-17 days) that were three standard deviations away from the mean were removed. These
230 outliers represented less than 1.5% of the dataset. For feed consumption after 17 days of age,
231 the number of kits was adjusted assuming that dead animals did not consume feed two days
232 before their death.

233 Voluntary feed intake measurements were used to determine feed preferences: relative
234 consumption (RC) was calculated for each pellet within a litter, which is the percentage
235 contribution of a pellet to the total feed intake. For example, in the treatment AB of a given
236 litter, the RC of pellet A was calculated as follows:

$$237 \quad RC_A = \left[\frac{\text{Amount of pellet A consumed}}{\text{Amount of pellet A consumed} + \text{Amount of pellet B consumed}} \right] * 100$$

238 This index was chosen to describe preferences because it is informative, intuitive and has
239 practical appeal (Lockwood III, 1998). RC values could represent total aversion (0%),
240 indifference (50%) or strong preference (100%; Seabolt et al., 2010). If RC was significantly
241 higher than the neutral value of 50%, then a preference for the given pellet was observed
242 inside the treatment. RC values of the first trial were calculated as of 13 days of age because

243 we encountered technical difficulties with the feeding system before this date (cups spilled by
244 the rabbits). In the second trial, RC values could be calculated from 8 to 35 days.

245 Statistics were performed with R software (R Core Team, 2018). One sample t-test
246 was performed to test the RC means compared to the neutral value of 50%. If the RC value
247 did not fit a normal distribution, Arcsine transformation was used. Comparison treatment
248 effect on feed intake, milk intake and growth performance was controlled to ensure that
249 preference responses could be compared between treatments by using one-way analysis of
250 variance. In the second trial, the intake of 2.5-mm pellets was also compared with the intake
251 of 4-mm pellets with ANOVA procedure. A linear mixed model was fitted to investigate
252 inter-litter variability of the feed consumption measurements in the second trial from 8 to 21
253 days since no milk data were available beyond this date. Daily milk data between 8 and 21
254 days were obtained with extrapolation of the farm measurements by modeling the lactation
255 curve with a quadratic model (Casado et al., 2006). Time, comparison treatment and nest
256 quality scores were set as fixed categorical factors, and litter weight at equalization and milk
257 consumption were set as quantitative cofactors; the litter was considered to be a random
258 effect. A linear mixed procedure was also applied on post-weaning data with comparison
259 treatment before weaning and rabbit sex as fixed effects, litter and fattening cage as random
260 effects. Mortality data was analyzed using adjusted chi-square according to the Donner and
261 Banting procedure (1989), so that litter cluster was accounted for (Reed, 2004; Princée, 2016).
262 Differences were considered to be significant when $P \leq 0.05$. If P-value was less than 0.10 but
263 greater than 0.05, then differences among means were considered to suggest a tendency.

264 **3. Results**

265 *3.1. Pellet physical characteristics*

266 Measurements of pellet physical characteristics are given in Table 3. In Trial 1, by
267 ranking in increasing order of hardness, we obtained pellets D, A, B and C (pellet C was 36%

268 harder than pellet D). In Trial 2, for the 2.5-mm-diameter pellet group, pellet G had a greater
269 hardness than pellets E and F (+ 0.3 MPa), whereas for the 4-mm diameter, pellet C was
270 softer than pellets H and I (- 0.2 MPa). These differences in hardness were related to the die
271 length-to-diameter ratio used: 5.6 for G (highest compression rate of its group) and 4.5 for C
272 (lowest compression rate of its group). Pellet D showed a notably low durability ($85.7 \pm$
273 1.1%) compared to the other pellets ($94.3 \pm 1.9\%$ on average).

274 *3.2. Feed and milk intake*

275 Considering the whole pellet intake, regardless of the comparison treatments in Trials
276 1 and 2, we observed that solid feed ingestion in the nest started at 8 **days of age**, with a mean
277 of 0.03 ± 0.03 g of DM consumed per kit (Fig. 4). One fourth of the litters did not start solid
278 feed intake at 8 **days**, while one day later, only 9% had not started. At **12 days of age**, all the
279 litters were consuming the pellets. Pellet intake progressively increased with age and reached
280 0.54 ± 0.19 g of DM per rabbit at **17 days**. Between 15 and 17 **days**, the feed was accessible
281 in both the nest and the feeders. The young rabbits preferred to consume feed in the nest
282 rather than in the feeders during this period ($+0.20$ g of DM/rabbit from 15 to 17 **days** in the
283 nest compared to the feeder origin; $P = 0.003$). Over the first 17 **days of life**, a rabbit
284 consumed a total of 1.63 ± 0.76 g of DM in the nest and a total of 2.50 ± 0.44 g of DM from
285 the pellets in both the nest and the feeders. In relation to fresh matter, the pellet intake from 8
286 to 17 **days** corresponded to 1.3% of the total milk intake over this period. The feed-to-milk
287 intake ratio increased from 0.1% of the milk intake at the beginning of the experiment (**day 8**),
288 to 2% of the milk intake at 17 **days of age**. Interestingly, post-natal feed intake was highly
289 variable between litters (CV = 89% for the total feed intake at 12 **days**, for example). A
290 statistical model was therefore built to determine which factors had an effect on the daily feed
291 intake using data obtained in the second trial until 21 **days of age**. Daily milk intake and nest
292 quality score did not affect the solid feed intake (NS). Instead, the body weight at 3 **days of**

293 age (average weight at 3 days: 109 ± 9 g/rabbit) correlated positively with the litter's post-
294 natal pellet consumption from 12 to 17 days ($P=0.003$), and the correlation coefficients
295 ranged from 0.3 to 0.5 (Fig. 5). After 21 days of age, the amount of feed consumed quickly
296 increased (Fig. 6) to reach 65 ± 14 g of DM per kit on average at weaning. Concomitantly, the
297 milk yield curve reached a plateau at around 21 days (292 ± 75 g of milk/doe).

298 The total feed intake in the feeders was similar between comparison treatments (Table
299 4) except at the beginning of the first trial (15 – 17 days). However, the precision of the mean
300 estimates for this period was low as indicated by the standard error of the mean (SEM). We
301 compared intake of 2.5-mm pellets vs. 4-mm pellets in Trial 2, a situation where no choice
302 between diameters was given (EF, EG and FH treatments compared to CH, CI and HI
303 treatments). Between 21 and 27 days, the 2.5-mm pellet intake tended to be higher than the 4-
304 mm pellet intake ($P = 0.068$), but no effect was observed from 15 to 35 days ($P = 0.645$).

305 *3.3 Pellet preferences*

306 RC value of the 6-mm-diameter pellet (D) was greater than 50% when offered with the
307 2-mm-diameter pellet (A) in the nest ($P=0.002$). No other preference was expressed in the
308 nest within treatments of the first trial (Fig. 7). In contrast with what was observed in the nest,
309 clear-cut aversion was found for pellet D compared to A, B (3.2 mm) and C (4 mm) in the
310 feeders, with RC values below 50% of total feed intake (RC of 14% in the double-choice
311 group AD, 28% in BD and 27% in CD; $P<0.001$; Fig.7). Relative consumption of A was
312 greater than 50% when it was offered against B (61%; $P=0.021$) and D (86%; $P<0.001$), and
313 tended to be greater than 50% compared to C (67%; $P=0.081$).

314 In the second trial, RC values within the double-choice groups EF, EG and FG did not
315 significantly differ from 50%, meaning that no preference was expressed throughout the
316 whole trial (Fig. 8). In the nest, slight avoidance was noticed for I compared to C (RC of 40%;
317 $P=0.014$, when compared to the 50% neutral value) but this response was no longer

318 significant in the feeders ($P=0.117$). When H was present with I in the feeders, the latter was
319 avoided since its relative consumption was less than 50% (39%; $P=0.020$).

320 *3.4 Health and growth performances according to treatments*

321 Throughout both trials, all animals remained healthy: the mortality was low (4.5%
322 from 3 to 35 **days** and 1.8% from 36 to 72 **days**) and was not affected by the pellets offered
323 before weaning (NS). Milk intake was similar between groups as well as feed intake from 18
324 **days of age** to weaning.

325 Growth performances are reported in Tables 5 and 6. Rabbit weights before weaning
326 were not affected by the comparison treatments (NS). Double-choice treatment had an effect
327 on the daily weight gain between 21 and 35 **days of age** in the first trial ($P = 0.039$), but the
328 Tukey follow-up test performed on the six group means was not significant for any pair of
329 means. The gender did not affect growth after weaning, thus the sex effect was removed from
330 the final model. Rabbit growth performances during the fattening period did not differ
331 between comparison treatments.

332 **4. Discussion**

333 We hypothesized that stimulating early solid feed intake would contribute to
334 preserving the health of young rabbits through a positive action on cecal microbiota
335 implantation. We thus aimed to, first, quantitatively describe early feed intake and, second, to
336 determine young rabbit pellet preferences according to their physical properties.

337 *4.1 Characterization of feed intake patterns*

338 To our knowledge, this study is the first to provide comprehensive quantitative data on
339 the solid intake of suckling rabbits. A nest feeding system was especially developed to
340 measure post-natal rabbit feed intake. Previous studies dealing with the feeding capacity of
341 young rabbits provided gradual amounts of pellets in the nest. They visually observed solid

342 intake (Kacsala et al., 2017) or measured the consumption by counting the number of feed
343 pellets left (Gidenne et al., 2013). By providing quantitative feed intake records, this study
344 provided new insights into the occurrence, magnitude and variability of this behavior.

345 Suckling rabbits were able to consume some feed pellets as of 8 **days of age**. Before
346 this age, the diet of young rabbits depends on milk supply alone. The absence of solid intake
347 during the first week might be explained by a lack of capability since mastication is functional
348 as of 13 **days** and kits are still learning to masticate until 4 weeks of age (Langenbach et al.,
349 2001). Furthermore, while the olfactory system is fully developed at birth, the onset of visual
350 functions is estimated to be at around 7-8 **days of age** (Gottlieb, 1971). These ontogenetic
351 parameters should be considered when developing feed adapted to the young rabbit, for
352 example, by adding sensory functional ingredients in the feed or by offering feed with an
353 optimal texture for the kit's masticatory system. In this study, pellet size and hardness were
354 investigated since we assumed that rabbits would prefer soft and small pellets because they
355 are easier to chew.

356 In the present study, we were able to determine the evolution of solid feed intake in
357 kits. As previously described (Gidenne et al., 2010), the amount of solid feed ingested outside
358 the nest remained low until 21 **days**, before a sharp increase. The early onset of solid feed
359 intake allowed by a nest feeding system did not modify this general pattern. In the nest, the
360 between-litter variability of the solid feed intake was high, especially in the early period. Our
361 results showed that the maternal ability of the doe, assessed together with milk intake and nest
362 quality, did not affect the early feeding in the nest or in the feeders. Bonachera et al. (2017)
363 found, on the contrary, that the higher the milk intake was during early lactation (0-17 **days**),
364 the higher the feed intake (17-28 **days**) was, which suggests that high milk intake could
365 promote solid intake. However, these authors did not study the correlation between the feed
366 intake and the corresponding milk intake at an early stage (before 17 **days of age**). At this age,

367 we hypothesized that other factors could explain dietary intake, including litter weight at
368 standardization, which was positively correlated with the early feed intake of the litter. At the
369 within-litter level, a similar conclusion was reached by Pajor et al. (1991) who studied the
370 variation of solid feed intake of suckling piglets. They demonstrated that piglets of high birth
371 weight ate more pre-weaning feed than their littermates of lower birth weight. This could be
372 explained by greater needs and a more developed digestive system in heavier animals (de
373 Passillé et al., 1989). However, these findings were not consistent with the research of
374 Bruininx et al. (2004) who did not report a relationship between the piglets' birth weight and
375 individual early feed consumption. Better knowledge of the animal related factors that affect
376 solid feed intake variability is of importance in order to increase both the number of rabbits
377 that exhibit early feed intake and the levels of ingestion.

378 *4.2 Pellet processing and effects on suckling rabbits' preferences*

379 This study attempted to analyze separately diameter and hardness effects by using
380 pellets with different diameters and constant compression rate, and vice versa. However,
381 hardness differences were found between pellets of different diameters in Trial 1, whereas the
382 pellet compression rates were similar. Inversely, for pellets in Trial 2 with the same diameter,
383 different compression rates led to similar hardness. These unexpected results might be
384 explained by the heterogeneity of the internal pellet structure inherently caused by the diverse
385 raw materials that make it up. Thomas and Van der Poel (1996) confirmed the large variation
386 of fragmentation-type measurements for a given hardness device. For this reason, hardness
387 measurements should be carefully interpreted. As expected, the pellet processing of this
388 experiment did not alter pellet chemical composition and hydration properties, which suggests
389 that post-ingestive effects were similar between feeds. Thus, dietary preferences were
390 considered to be a good indicator of feed palatability, which is defined as the "physical and
391 chemical properties of the diet that are associated with promoting or suppressing feeding

392 behavior during the pre-absorptive or immediate post-absorptive period” (McArthur et al.,
393 1993). In the first trial, results suggested a shift of preferences between the nest and the
394 feeder, with a slight preference for the pellet with the greatest diameter over the lowest (6.0
395 mm over 2.0 mm) in the first days of the experiment, whereas the rabbits rejected 6.0-mm-
396 diameter pellets a few days before weaning. The initial preference expressed for the 6.0-mm
397 pellets may be explained by an overestimation of their intake due to their low durability
398 index. Indeed, pellets of low durability produce a greater amount of fines, which are not
399 consumed by the rabbits (Maertens, 2010) but are counted as consumed with food weighing
400 method. Pellet durability could not be controlled with our experimental design during the
401 pelletizing since die size has an intrinsic effect on durability (Oduntan and Koya, 2016). In the
402 feeders, we were able to rank the pellets by order of preference: first: 2.0-mm-diameter
403 pellets; second: 3.0- and 4.0-mm-diameter pellets; and third: 6.0-mm-diameter pellets.
404 Regarding pellet physical properties, pellets with diameters ranging between 2.0 and 4.0 mm
405 had similar hardness, durability and hydration properties, so we could therefore conclude that
406 the higher palatability of 2.0-mm-diameter pellets was due to their small diameter. Pellet
407 presentation can modify feed sensory characteristics such as appearance and feed texture
408 sensation. Ease of prehension of small pellets may partly explain their attractiveness for the
409 litters since rabbits are known to eat pellets one by one (Maertens, 1994). Regarding the
410 largest pellets, they were found to have a low durability index, which could negatively affect
411 their palatability since rabbits do not like fines as previously discussed. Therefore, it remains
412 unclear to what degree the large diameter of these pellets is responsible for their low
413 palatability. In the second trial, rabbits slightly avoided eating the 4.0-mm-diameter pellet
414 processed with the highest compression rate when facing another kind of 4.0-mm-diameter
415 pellet. However, this avoidance was only visible in one of the two comparison combinations
416 in the nest and in the feeders. Limited statistical power due to the sample size used in the

417 present study (n = 10 litters) may have reduced the chance to detect moderate magnitude
418 preferences for pellets with a lower compression rate both in the nest and the feeders. Physical
419 measurements performed on the pellet with the highest compression rate did not highlight any
420 specific characteristics when compared to other 4.0-mm-diameter pellets. Consequently, the
421 effects of compression rate on pellet palatability still need to be investigated.

422 Overall, in the present study, no clear preference pattern in the nest was determined.
423 The small quantity of feed consumed in the nest, which requires high measurement accuracy,
424 may explain why we did not detect preferences. This phenomenon can also be explained by
425 the low activity of the kits during the two first weeks of life: their exploration of the nest is
426 limited at that time and feed consumption probably occurred randomly. In contrast, in the
427 feeders, suckling rabbits were able to differentiate pellets according to their diameter.

428 *4.3 Stimulation of the early feed intake and implications*

429 Currently, rabbit pellets are manufactured with a diameter of 3.0 or 4.0 mm (Acedo-
430 Rico et al., 2010). High palatability of 2.0-mm-diameter pellets in the present study suggests
431 that a preferential use of small-diameter pellets could be advocated to stimulate early
432 consumption. However, some studies have pointed out that when domestic caged rabbits
433 expressed a preference for a specific feed rather than another, the daily feed intake could be
434 similar between the two types of feed once they were offered alone (Gidenne et al., 2010).
435 Nevertheless, these studies were performed on fattening rabbits, and suckling rabbits may
436 present specific feed intake regulations. In the first double-choice trial, total feed intakes of
437 treatments providing the smallest pellet did not differ from the feed intake of other treatments,
438 **except between 15 and 17 days (however those results might be meaningless due to low**
439 **precision)**. It could suggest that the higher palatability of the small pellets is not sufficient to
440 increase feed intake. On the contrary, in the second trial in this study, there was a trend
441 towards a higher feed intake in the feeders for the treatments with 2.5-mm pellets when

442 compared to treatments with 4.0-mm pellets. Experiments where one kind of pellet is tested
443 per litter (no-choice tests) are now required to ensure that the feed intake increases with small
444 pellets **and to evaluate further consequences on rabbits growth.**

445 In the current study, the onset of solid feed was advanced by eight days compared to
446 conventional rabbitries where the solid feed intake behavior starts at around 16 days of age
447 (Gidenne and Fortun-Lamothe, 2002). The substrates precociously reaching the gut from the
448 solid feed are likely to stimulate the microbiota implantation process. Indeed, it was shown
449 that intake of fecal pellets left behind by the doe in the first 10 days after delivery plays a role
450 in cecal microbiota colonization (Kovács et al., 2006; Combes et al., 2014), even if the
451 ingestion is small (a mean of ten fecal pellets per litter with free milking conditions). The feed
452 is also a key factor for microbiota activity, as highlighted by Kovács et al. (2006) through an
453 early weaning experiment: when the rabbit solid feed intake was stimulated as of 21 **days of**
454 **age** by preventing milk supply, the cecal microbiota fermentation activity significantly
455 increased. Seeding the microbiota of neonatal gut with healthy commensal bacteria is
456 essential to optimize rabbit health since it is known that microbiota strongly interacts with
457 mammal health (Mage et al., 2006; Combes et al., 2018). The effect of early feeding on the
458 rabbit health needs to be further investigated since it could not be studied with our
459 experimental design (all the litters had access to pellets as of 3 **days of age**).

460 **5. Conclusion**

461 Intake of supplemental solid feed provided in the nest was observed as of 8 **days of age**. The
462 high variability of feed consumed during the early suckling period was partially explained by
463 the litter weight at the beginning of the experiment: heavier litters were associated with higher
464 solid feed intake at two weeks of age. Outside the nest, suckling rabbits were able to
465 discriminate pellets according to their diameter with the following preferences: 2 mm > (3.2
466 and 4 mm) > 6 mm diameter pellets. The effect of compression rate on the kits' feeding

467 behavior needs to be further investigated. In terms of implications, this research shows that it
468 is possible to promote post-natal feed intake through a nest feeding system and that pellet
469 palatability can be improved before weaning with an optimal presentation. The acceleration
470 and the increase in the solid intake before weaning could contribute to the acquisition and
471 maturation of the kit microbiota and, hence, contribute to improved health.

472 Declarations of interest: none

473 **Acknowledgments**

474 This work was supported by the Institut Carnot Santé Animale [eFeedIT-ICSA-2015].
475 The authors gratefully acknowledge the assistance of M. Moulis and J-M Bonnemere at the
476 rabbit experimental unit, as well as the technical help of M. Segura for starch analysis (INRA,
477 GenPhySE unit). They also would like to thank F. Enjalbert for constructive criticism of the
478 manuscript (ENVIT, GenPhySE unit).

479 **References**

480 Acedo-Rico, J., Méndez, J., Santomá, G., 2010. Feed Manufacturing, in: De Blas, C.,
481 Wiseman, J., 2010. The nutrition of the rabbit, 2nd edition. CAB International,
482 Wallingford, UK, pp. 200-221.

483 AFNOR, 1997. Norme Française homologuée. Aliments des animaux - Détermination
484 séquentielle des constituants pariétaux. Méthode par traitement aux détergents neutre
485 et acide et à l'acide sulfurique. AFNOR, PARIS, NF V 18-122.

486 Anonymous, 2013. Décret n° 2013-118 du 1er février 2013 relatif à la protection des animaux
487 utilisés à des fins scientifiques. JORF n°0032 du 7 février 2013.
488 <https://www.legifrance.gouv.fr/eli/decret/2013/2/1/AGRG1231951D/jo/texte>
489 (accessed 17 June 2019).

490 Anonymous, 2010. Directive 2010/63/EU of the European Parliament and of the Council of
491 22 September 2010 on the protection of animals used for scientific purposes. OJ L
492 276, 33–79.

493 Arroyo, J., Auvergne, A., Dubois, J.P., Lavigne, F., Bijja, M., Bannelier, C., Fortun-Lamothe,
494 L., 2012. Effects of presentation and type of cereals (corn or sorghum) on performance
495 of geese. *Poult. Sci.* 91, 2063–2071.

496 Bäuerl, C., Collado, M.C., Zúñiga, M., Blas, E., Martínez, G.P., 2014. Changes in Cecal
497 Microbiota and Mucosal Gene Expression Revealed New Aspects of Epizootic Rabbit
498 Enteropathy. *PLoS One.* 9(8), e105707.

499 Bonachera, A.A., Cervera, C., Martínez-Paredes, E., Ródenas, L., Pascual, J.J., Blas, E., 2017.
500 Milk intake in kits: not only the total amount matters. *World Rabbit Sci.* 25, 159–166.

501 Bruininx, E.M.A.M., Schellingerhout, A.B., Binnendijk, G.P., van der Peet-Schwering,
502 C.M.C., Schrama, J.W., den Hartog, L.A., Everts, H., Beynen, A.C., 2004.
503 Individually assessed creep food consumption by suckled piglets: influence on post-
504 weaning food intake characteristics and indicators of gut structure and hind-gut
505 fermentation. *Anim. Sci.* 78, 67–75.

506 Casado, C., Piquer, O., Cervera, C., Pascual, J.J., 2006. Modelling the lactation curve of
507 rabbit does: Towards a model including fit suitability and biological interpretation.
508 *Livest. Sci.* 99, 39–49.

509 Combes, S., Fortun-Lamothe, L., Cauquil, L., Gidenne, T., 2013. Engineering the rabbit
510 digestive ecosystem to improve digestive health and efficacy. *Animal.* 7, 1429–1439.

511 Combes, S., Gidenne, T., Boucher, S., Fortun-Lamothe, L., Bolet, G., Coureaud, G., 2018.
512 Pour des lapereaux plus robustes au sevrage: des bases biologiques aux leviers
513 d’action en élevage. *INRA Productions Animales.* 31(2), 105-116.

514 Combes, S., Gidenne, T., Cauquil, L., Bouchez, O., Fortun-Lamothe, L., 2014. Coprophagous
515 behavior of rabbit pups affects implantation of cecal microbiota and health status. *J.*
516 *Anim. Sci.* 92, 652–665.

517 De Passillé, A.M., Pelletier, G., Ménard, J., Morisset, J., 1989. Relationships of weight gain
518 and behavior to digestive organ weight and enzyme activities in piglets. *J. Anim. Sci.*
519 67, 2921–2929.

520 Donner, A., Banting, D., 1989. Adjustment of Frequently Used Chi-square Procedures for the
521 Effect of Site-to-Site Dependencies in the Analysis of Dental Data. *J. Dent. Res.* 68,
522 1350–1354.

523 EGRAN, 2001. Technical note: Attempts to harmonise chemical analyses of feeds and faeces,
524 for rabbit feed evaluation. *World Rabbit Sci.* 9, 57–64.

525 Fortun-Lamothe, L., Boullier, S., 2007. A review on the interactions between gut microflora
526 and digestive mucosal immunity. Possible ways to improve the health of rabbits.
527 *Livest. Sci.* 107, 1–18.

528 Fortun-Lamothe, L., Gidenne, T., Lapanouse, A., De Dapper, J., 2000. Technical note : An
529 original system to separately control litter and female feed intake without modification
530 of the mother - young relations. *World Rabbit Sci.* 8, 177–180.

531 Gidenne, T., Combes, S., Fortun-Lamothe, L., Zemb, O., 2013. Capacité d'ingestion
532 d'aliment sec par le lapereau au nid: Interaction avec l'ingestion de fèces dures
533 maternelles. In: Proc. 15èmes Journées de la Recherche Cunicole, ITAVI, Le Mans,
534 pp. 89-92.

535 Gidenne, T., De Dapper, J., Lapanouse, A., Aymard, P., 2007. Adaptation du lapereau à un
536 aliment fibreux distribué avant sevrage: comportement d'ingestion, croissance et santé
537 digestive. In: Proc. 12èmes Journées de la Recherche Cunicole, ITAVI, Le Mans, pp.
538 109-112.

539 Gidenne, T., Fortun-Lamothe, L., 2002. Feeding strategy for young rabbit around weaning: a
540 review of digestive capacity and nutritional needs. *Anim. Sci.* 75, 169–184.

541 Gidenne, T., Lebas, F., Fortun-Lamothe, L., 2010. Feeding behaviour of rabbits, in: De Blas,
542 C., Wiseman, J. (Eds.), *Nutrition of the Rabbit*. CABI, Wallingford, UK, pp. 233–252.

543 Giger Reverdin, S., 2000. Characterisation of feedstuffs for ruminants using some physical
544 parameters. *Anim. Feed Sci. Technol.* 86, 53–69.

545 Gottlieb, G., 1971. Ontogenesis of sensory function in birds and mammals, in: Tobach, E.,
546 Aronson, L., Shaw, E. (Eds.), *The Biopsychology of Development*. Academic Press,
547 New York, pp. 67–128.

548 Kacsala, L., Szendrő, Z., Gerencsér, Z., Radnai, I., Kovács, M., Kasza, R., Nagy, I., Odermatt,
549 M., Atkári, T., Matics, Z., 2017. Early solid additional feeding of suckling rabbits
550 from 3 to 15 days of age. *Animal*.12, 28-33.

551 Koenig, J.E., Spor, A., Scalfone, N., Fricker, A.D., Stombaugh, J., Knight, R., Angenent,
552 L.T., Ley, R.E., 2011. Succession of microbial consortia in the developing infant gut
553 microbiome. *Proc. Natl. Acad. Sci. U.S.A.* 108 Suppl 1, 4578–4585.

554 Konstantinov, S.R., Favier, C.F., Zhu, W.Y., Williams, B.A., Kluss, J., Souffrant, W.B., de
555 Vos, W.M., Akkermans, A.D.L., Smidt, H., 2004. Microbial diversity studies of the
556 porcine gastrointestinal ecosystem during weaning transition. *Anim. Res.* 53, 317–
557 324.

558 Kovács, M., Szendrő, Zs., Milisits, G., Biro-Nemeth, E., Radnai, I., Posa, R., Bonai, A.,
559 Kovacs, F., Horn, P., 2006. Effect of nursing method and faeces consumption on the
560 development of bacetroides, lactobacillus and coliform flora in the caecum of the
561 newborn rabbits. *Reprod. Nutr. Dev.* 46, 205–210.

562 Kozłowski, F., 1994. L'amidon, quel dosage pour quel échantillon. *Cah. Techn. INRA.* 35, 5–
563 22.

564 Langenbach, G.E., Weijs, W.A., Brugman, P., van Eijden, T.M., 2001. A longitudinal
565 electromyographic study of the postnatal maturation of mastication in the rabbit. Arch.
566 Oral Biol. 46, 811–820.

567 Lebas, F., Lamboley, B., 1999. Liquid phase sifting determination of the size of particles
568 contained in pelleted rabbits feeds. World Rabbit Sci. 7, 229–235.

569 Lockwood III, J.R., 1998. On the statistical analysis of multiple-choice feeding preference
570 experiments. Oecologia. 116, 475-481.

571 Maertens, L., 2010. Feeding systems for intensive production, in: De Blas, C., Wiseman, J.
572 (Eds.), Nutrition of the Rabbit. CABI, Wallingford, UK, pp. 253–266.

573 Maertens, L., 1994. Influence du diamètre du granulé sur les performances des lapereaux
574 avant sevrage. In: Proc. 6èmes Journées de la Recherche Cunicole, ITAVI, La
575 Rochelle, pp. 325–332.

576 Mage, R.G., Lanning, D., Knight, K.L., 2006. B cell and antibody repertoire development in
577 rabbits: The requirement of gut-associated lymphoid tissues. Dev. Comp. Immunol.
578 30, 137–153.

579 McArthur, L.H., Kelly, W.F., Gietzen, D.W., Rogers, Q.R., 1993. The Role of Palatability in
580 the Food Intake Response of Rats Fed High-Protein Diets. Appetite. 20, 181–196.

581 Méheust, D., Chevance, A., Moulin, G., 2017. Suivi des ventes de médicaments vétérinaires
582 contenant des antibiotiques en France en 2016. Rapport annuel. [https://hal-
583 anses.archives-ouvertes.fr/anses-01612084](https://hal-anses.archives-ouvertes.fr/anses-01612084) (accessed 14 June 2019).

584 Oduntan, O.B., Koya, O.A., 2016. Effect of speed, die sizes and moisture contents on
585 durability of cassava pellet in pelletizer. Res. Agr. Eng. 61, 35-39.

586 Orengo, J., Gidenne, T., 2005. Comportement alimentaire et caecotrophie chez le lapereau
587 avant sevrage. In: Proc. 11èmes Journées de la Recherche Cunicole, ITAVI, Paris, pp
588 45–48.

589 Padilha, M.T.S., Licois, D., Gidenne, T., Carré, B., 1999. Caecal microflora and fermentation
590 pattern in exclusively milk-fed young rabbits. *Reprod. Nutr. Dev.* 39, 223–230.

591 Padilha, M.T.S., Licois, D., Gidenne, T., Carré, B., Fonty, G., 1995. Relationships between
592 microflora and caecal fermentation in rabbits before and after weaning. *Reprod. Nutr.*
593 *Dev.* 35, 375–386.

594 Pajor, E.A., Fraser, D., Kramer, D.L., 1991. Consumption of solid food by suckling pigs:
595 individual variation and relation to weight gain. *Appl. Anim. Behav. Sci.* 32, 139–155.

596 Princée, F.P.G., 2016. Exploring Studbooks for Wildlife Management and Conservation, in:
597 Princée, F.P.G (Ed), *Inbreeding*. Springer International Publishing, Norfolk, UK. pp.
598 185-186.

599 Reed, J.F., 2004. Adjusted Chi-Square Statistics: Application to Clustered Binary Data in
600 Primary Care. *Ann. Fam. Med.* 2, 201–203.

601 Seabolt, B.S., van Heugten, E., Kim, S.W., Ange-van Heugten, K.D., Roura, E., 2010. Feed
602 preferences and performance of nursery pigs fed diets containing various inclusion
603 amounts and qualities of distillers coproducts and flavor. *J. Anim. Sci.* 88, 3725–3738.

604 Sekirov, I., Finlay, B.B., 2009. The role of the intestinal microbiota in enteric infection. *J.*
605 *Physiol.* 587, 4159–4167.

606 Tan, C., Wei, H., Zhao, X., Xu, C., Peng, J., 2017. Effects of dietary fibers with high water-
607 binding capacity and swelling capacity on gastrointestinal functions, food intake and
608 body weight in male rats. *Food. Nutr. Res.* 61, 1308118.

609 Thomas, M., Van der Poel, A.F.B., 1996. Physical quality of pelleted animal feed 1. Criteria
610 for pellet quality. *Anim. Feed Sci. Technol.* 61, 89–112.

611 Travel, A., Mirabito, L., Chanay, I., Souchet, C., Galliot, P., Weissman, D., Corrent, E.,
612 Davoust, C., 2009. Préférences alimentaires du lapereau selon le diamètre du granulé,

613 dans le cadre d'une alimentation séparée mère-jeunes. In : Proc. 13ème Journées de la
614 Recherche Cunicole, ITAVI, Le Mans, pp 2-5.

615 Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral
616 detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy
617 Sci. 74, 3583–3597.

618

619 **Fig. 1.** Housing used to control separately the doe's feed intake and that of its litter, with a limited
620 access to the nest box for the doe. On the top is mapped the view of the cage seen from the top. Below
621 is represented the view of the same cage seen from left side.

622

623 **Fig. 2.** View of the nest box when rabbits were 4-days old. The two cups on the right contained two
624 types of feed pellets differing in either diameter (Trial 1) or compression rate (Trial 2).

625

626 **Fig. 3.** Experimental design used to characterize suckling rabbit intake and pellet preferences.

627

628 **Fig. 4.** Dynamic of feed consumption in 8 to 17-day-old rabbits receiving pellets in the nest as of 3
629 days of age (Trials 1 and 2). From 15 to 17 days, feed was also available in feeders outside the nest.
630 The intake is the sum of the consumptions of the two types of pellets tested. Results are presented as
631 the mean and standard deviation. The different letters stand for significant differences ($P < 0.05$).

632

633 **Fig. 5.** Relationship between starter feed intake and litter weight (at 3 days of age) in Trial 2. The total
634 feed intake from 12 to 14 days is represented on the left, and the total feed intake from 15 to 17 days is
635 represented on the right. Dot size is proportional to milk consumption.

636 r stands for the Pearson Correlation, P for the significance level of the correlation, and N for the
637 sample size.

638

639 **Fig. 6.** Feed and milk consumption of suckling rabbits receiving solid pelleted feed as of 3 days of age
640 (Trials 1 and 2). For each litter, the intake is the sum of the consumptions of the two pellets tested.
641 Results are presented as the mean and standard deviation.

642

643 **Fig. 7.** Relative pellet consumption in the nest (A) and in the feeders (B) for the first trial. The animals
644 had the choice between two pellets that differed in diameter (A: 2 mm; B: 3.2 mm; C: 4 mm; and D: 6
645 mm). Results are presented as the mean and standard deviation.

646 The symbols represent significantly different preference values (\dagger : $P < 0.1$; *: $P < 0.05$; **: $P < 0.01$;
647 ***: $P < 0.001$).

648

649 **Fig. 8.** Relative pellet consumption in the nest (A) and in the feeders (B) for the second trial. The
650 young rabbits had the choice between two pellets of the same diameter (E, F, G: 2.5 mm, and C, H, I:
651 4 mm) that differed by compression rate. Results are presented as the mean and standard deviation.

652 The symbols represent preference values significantly different by 50% (*: $P < 0.05$).

653

654
655

Table 1 Ingredients and chemical composition of the experimental meals.

	Kits ^a	S.E. ^a	Does
Ingredients (g/kg as-fed basis)			
Wheat	50		54
Barley	148		120
Wheat bran	150		300
Rapeseed whole seed	20		
Rapeseed meal	82		100
Rapeseed oil	5		2
Sunflower whole seed			73
Sunflower meal	240		120
Sunflower husk			77
Alfalfa meal	112		
Sugar beet pulp	110		76
Sugar beet molasses			50
Apple pomace	27		
Cane molasses	30		
Sodium chloride			6
Dicalcium phosphate	1		
Calcium carbonate	6		
L-Lysine, 20%	5		3
Methionine, 15%			2
Threonine, 20%			12
Mineral and vitamin premix ^b	10		5
Cocciostat ^c	5		
Chemical composition (g/kg as-fed basis)			
Dry matter	909	7.4	890
Ash	81	5.6	80
Crude protein	176	2.3	172
aNDFom ^d	337	5.9	316
ADFom ^e	189	3.3	176
Lignin (sa) ^f	72	1.2	53
Starch	52	3.8	86
Fat content	33	0.6	27
Gross energy (MJ/kg)	17.0	0.3	16.4

656 ^a Means and standard errors for chemical composition of the nine pre-weaning pellets.

657 ^b Premix provided per kg of complete feed: vitamin A, 10,000 IU; vitamin D3, 1000 IU; vitamin E, 50.

658 IU; Cu, 10 mg; Fe, 100 mg; Zn, 50 mg; Mn, 5 mg; I, 0.2 mg; Co, 0.1 mg; Se, 0.2 mg.

659 ^c Containing 0.5% diclazuril.

660 ^d Neutral detergent fiber expressed exclusive of residual ash.

661 ^e Acid detergent fiber expressed exclusive of residual ash.

662 ^f Lignin obtained with sulfuric acid method.

663

664 **Table 2** Pellet press dies specifications used to process young rabbit feeds.
 665

Pellet	Trial	Die specification		
		Channel diameter (mm)	Channel length (mm)	Length-to-diameter ratio
A	1	2	10	5
B	1	3.2	16	5
C	1 and 2	4	18	4.5
D	1	6	24	4
E	2	2.5	10	4
F	2	2.5	12	4.8
G	2	2.5	14	5.6
C	1 and 2	4	18	4.5
H	2	4	20	5
I	2	4	24	6

666

667 **Table 3** Physical characteristics of the pellets processed with nine different dies.

668

	Trial 1					Trial 2				Trial 2			669
	A	B	C	D	SEM	E	F	G	SEM	C	H	I	SEM
Die length-to-die width ratio	5	5	4.5	4	NC	4	4.8	5.6	NC	4.5	5	6	NC
Diameter (mm)	2.0	3.0	4.0	6.0	0	2.5	2.5	2.5	0	4.0	4.0	4.0	0
Length (mm)	8.9	8.6	8.8	9.4	0.5	8.2	8.8	8.5	0.2	8.8	8.2	8.5	0.2
Hardness (MPa)	1.19	1.36	1.45	1.06	0.15	1.54	1.52	1.76	0.09	1.45	1.69	1.66	0.11
Durability (%)	95.4	94.8	92.2	85.7	2.3	93.3	95.14	95.4	1.8	92.2	93.8	93.9	1.4
WHC ^a (g of H ₂ O/g of DM)	4.70	5.02	4.95	5.07	0.14	4.96	4.94	5.04	0.27	4.95	5.07	5.28	0.10
SC ^b (ml of H ₂ O/g of DM)	4.98	4.86	4.39	4.16	0.42	4.29	4.24	4.41	0.25	4.39	4.21	4.64	0.36
Particle size distribution (%)													677
> 1 mm	45.7	47.5	43.4	40.5	2.8	46.4	45.4	46.9	2.3	43.4	44.8	48.0	2.8
0.5-1 mm	8.9	13.4	10.8	10.3	1.6	10.2	10.7	10.7	1.2	10.8	11.3	10.9	2.1
0.3-0.5 mm	6.9	6.6	5.6	7.2	1.4	8.1	5.9	6.1	1.7	5.6	4.2	5.8	2.3
< 0.3 mm	38.5	32.5	40.3	42.0	2.3	35.3	37.9	36.4	1.5	40.3	39.8	35.3	2.6

681

682 ^a WHC: Water holding capacity.

683 ^b SC: Swelling capacity.

684 **Table 4** Effects of the physical properties of the pellets on the feed intake in the feeders from 15 to 35
 685 days (weaning). Values are means of the amount of solid feed ingested per rabbit per day. Means
 686 denoted by a different letter indicate significant differences between treatments.
 687
 688

Trial 1.								
	Double comparison groups						SEM	P-value
	AB	AC	AD	BC	BD	CD		
Feed intake (g of DM/rabbit/day)								
15-17 days	0.3 ^{ab}	0.4 ^{ab}	0.5 ^b	0.2 ^a	0.3 ^{ab}	0.2 ^{ab}	0.26	0.025
18-24 days	5	5	6	4	4	5	1.29	0.257
25-31 days	32	31	23	27	28	27	6.30	0.199
32-35 days	NC	NC	NC	56	59	57	NC	NC

Trial 2.								
	Double comparison groups						SEM	P-value
	EF	EG	FG	CH	CI	HI		
Feed intake (g of DM/rabbit/day)								
15-17 days	0.9	0.7	0.8	0.9	1.0	0.7	0.30	0.349
18-24 days	6	6	5	5	4	5	1.63	0.387
25-31 days	41	39	37	40	36	36	5.32	0.523
32-35 days	62	59	61	61	63	52	10.7	0.563

689

690

NC: not calculable because we ran out of pellet A as of 32 days.

691

692
693

Table 5 Effects of physical properties of the pellets on growth performance before weaning.

Trial 1.								
	Double comparison groups						SEM	P-value
	AB	AC	AD	BC	BD	CD		
Number of litters	10	8	10	10	10	10		
Live weight (g/rabbit)								
3 days	86	86	84	86	85	84	7	0.976
10 days	171	176	168	173	177	174	16	0.941
14 days	222	229	216	222	234	224	20	0.689
21 days	302	317	303	311	326	309	28	0.687
28 days	532	558	525	509	530	520	42	0.511
Average daily gain (g/d)								
3 – 21 days	12.0	12.8	12.2	12.5	13.4	12.5	1.4	0.627
21 – 35 days	38.6	38.4	33.8	33.6	35.6	35.9	3.3	0.039
Feed conversion ratio								
21 – 28 days	0.46	0.50	0.54	0.47	0.49	0.52	0.05	0.081
28 – 35 days	NC	NC	NC	1.04	1.04	0.97	NC	NC
Trial 2.								
	Double comparison groups						SEM	P-value
	EF	EG	FG	CH	CI	HI		
Number of litters	10	11	11	10	11	10		
Live weight (g/rabbit)								
4 days	110	112	108	109	105	107	7	0.713
14 days	280	279	269	282	273	272	22	0.880
21 days	381	385	378	387	378	372	31	0.960
28 days	646	643	628	639	606	601	44	0.353
Average daily gain (g/d)								
4 – 21 days	15.9	16.1	15.9	16.4	16.0	15.5	1.5	0.967
21 – 35 days	43.2	40.1	40.6	40.1	40.8	37.0	3.5	0.140
Feed conversion ratio								
21 – 28 days	0.46	0.47	0.46	0.45	0.42	0.48	0.06	0.660
28 – 35 days	1.14	1.20	1.13	1.22	1.09	1.15	0.10	0.226

694

695

NC: not calculable because we ran out of pellet A as of 32 days.

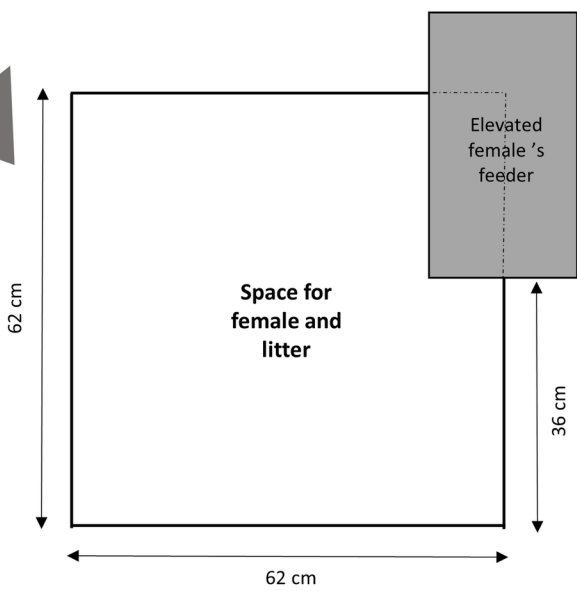
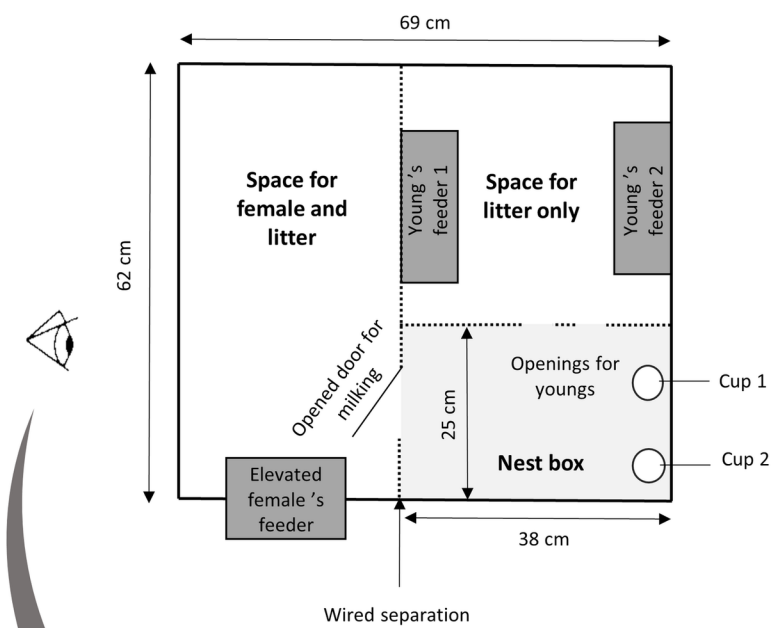
696

697
698

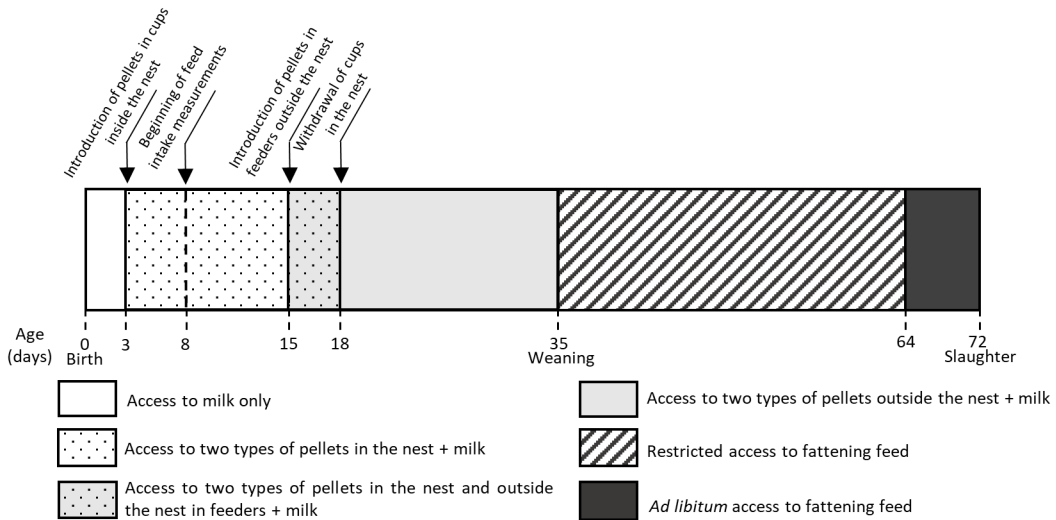
Table 6 Effects of physical properties of the pellets on rabbit growth performance after weaning.

Trial 1.								
	Double comparison groups						SEM	P-value
	AB	AC	AD	BC	BD	CD		
Number of rabbits at weaning	98	75	92	93	85	89		
Live weight (g/rabbit)								
35 days	842	859	777	782	824	812	58	0.118
50 days	1225	1259	1195	1222	1227	1196	46	0.487
64 days	1808	1907	1822	1824	1855	1798	67	0.517
Average daily gain (g/d)								
35–50 days	25	27	28	29	27	26	3	0.259
50–64 days	41	46	44	43	45	43	3	0.370
Trial 2.								
	Double comparison groups						SEM	P-value
	EG	FG	EF	CH	CI	HI		
Number of rabbits at weaning	102	102	74	91	89	81		
Live weight (g/rabbit)								
35 days	986	947	934	889	948	959	62	0.228
50 days	1506	1510	1552	1511	1512	1477	43	0.591
64 days	2132	2138	2218	2152	2130	2133	61	0.518
Average daily gain (g/d)								
35–50 days	37	37	38	35	38	39.	2	0.784
50–64 days	44	45	47	45	44	47	3	0.344

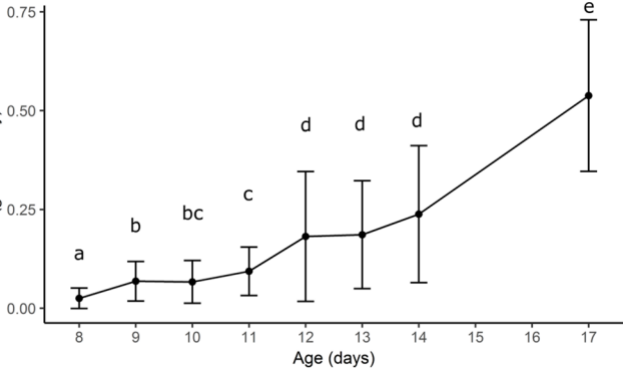
699

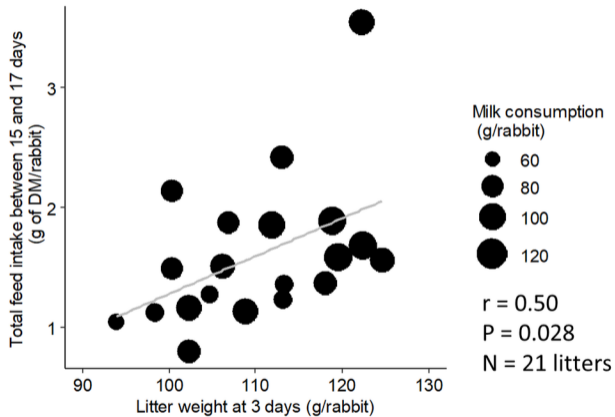
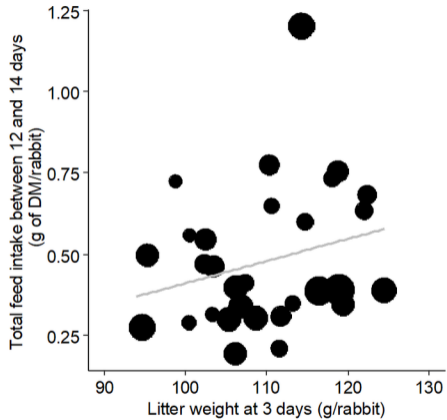




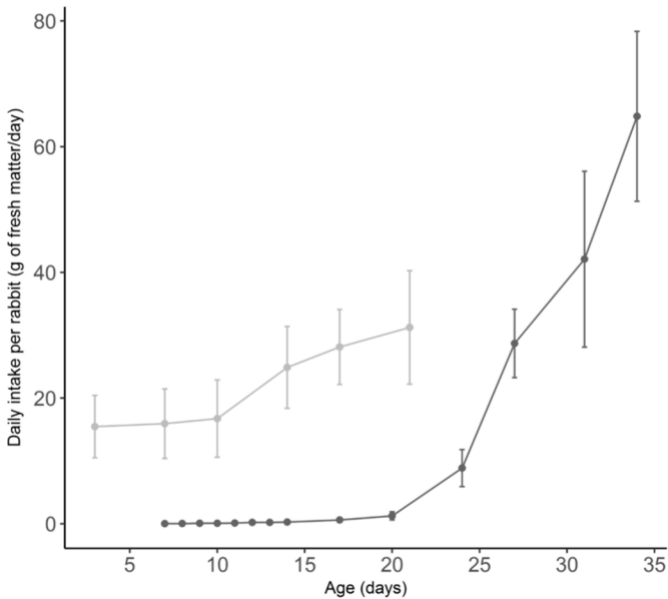


Solid feed intake per rabbit
(g of DM/day)

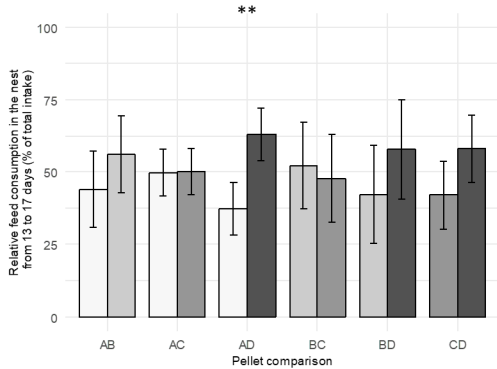




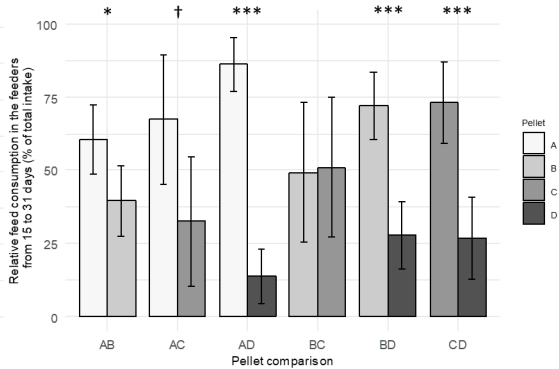
—●— Milk intake —●— Pellet feed intake



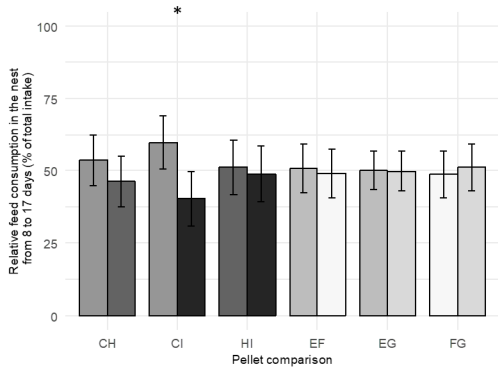
A) in the nest



B) in the feeders



A) in the nest



B) in the feeders

