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Insights into suckling rabbit feeding behaviour: acceptability of different creep feed presentations and attractiveness for sensory feed additives

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In young rabbit, digestive disorders are frequently observed around weaning. Stimulating the onset of feed intake in the suckling rabbit might be a way to promote gut health. The aim of this study was to determine the rabbit's acceptability for different feed presentations and its preferences for flavours at an early stage of life. Two trials were conducted to evaluate the effects of physical form and flavouring on creep feed attractiveness. All the diets tested were provided in the nest from 3 to 17 days, and the daily intake per litter was recorded as of 8 days of age. In the first trial, five feed presentations were tested separately (n = 60 litters). Three dry presentations were chosen: commercial pellet (P), crumb from commercial pellet (cP) and crumb from beet pulp pellet (cBP). Hydrated feeds were also provided with either raw fodder beetroot (B) or a semi-solid feed in agar gel form produced with fodder beetroot juice and pulp (gB). In the second trial, double-choice tests were performed on four feed gels (n = 72 litters), leading to six comparison treatments. These agar gels were made of pellet mash without or with a sensory additive: one non-odorised control gel and three gels with 0.20% banana flavour, 0.06% red berry flavour and 0.10% vanilla flavour, respectively. In the first trial, kits ate more gB in fresh matter than other feed presentations (P < 0.001), with a total intake of 7.0 ± 1.8 g/rabbit from 8 to 17 days. In DM, the total consumption of pellets P (1.6 ± 0.4 g of DM/rabbit) was the highest together with the gB form (1.4 ± 0.4 g of DM/rabbit), whereas cBP was barely consumed (0.3 ± 0.1 g of DM/rabbit). Gel feed supplemented with vanilla was slightly more consumed than other flavoured and non-odorised gels (relative consumption of 57% when compared to control gel; P = 0.001). The gel feed intake was independent of the milk intake but was correlated with the litter weight at 3 days (r = 0.40, P < 0.001). In both trials, rabbit growth before and after weaning was not affected by the type of creep feed provided. Our results confirmed that providing creep feed promotes the solid intake of rabbits at early stages. Gel feed form motivated rabbits to eat and vanilla flavour supplementation increased the feed palatability. Those creep feed characteristics should be explored further for seeking effective stimulation of the onset of the feed intake in suckling rabbit.

Keywords: rabbit kit, creep feed, solid feed intake, preference, flavouring additive

Implication

In order to stimulate the onset of the feed intake as a way to promote gut health, this study aimed to determine the most suitable feed presentation for suckling rabbits. Our findings suggest that technological solutions with high water content and low hardness should be considered when manufacturing creep feed. Moreover, our results have shown that some flavouring compounds, such as vanilla flavour, may influence

creep feed attractiveness for young rabbits. Hence, our trials pave the way for further studies on early nutritional control of the young rabbit health status.

Introduction

In commercial rabbit farming, digestive disorders are frequently observed around weaning and are the major cause of mortality (Marlier *et al.*, 2003). A survey conducted in French rabbitries in

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2017 revealed that the mortality rate between birth and sale reached 25% with 9% of deaths observed after weaning (Lebas, 2018). To reduce economic losses and decrease the use of antibiotic treatments, a new system to manage young rabbits is urgently needed.

Rabbits encounter several challenges during weaning: besides that they have to become behaviourally independent from their mothers and to adapt to exclusive solid diets rich in starch and vegetal proteins, they might face new housing and companions (Combes *et al.*, 2018). In pig industry, extensive research is devoted to nutritional strategies targeting a smooth transition from milk to dry feeds in order to alleviate weaning stress (Pluske *et al.*, 2005).

In rabbit farms, solid feed is introduced in the pre-weaning period, but to our knowledge, no feeding system adapted to suckling kits has been developed yet. Therefore, young rabbit usually starts to consume pellets as of 16 to 18 days of age when it is able to leave the nest and catch pellets in the doe's feeder (Gidenne and Fortun-Lamothe, 2002), whereas some experiments revealed the kit's ability to ingest solid substrate as early as 3 days (Combes *et al.*, 2014; Kacsala *et al.*, 2018). To develop new management practices, attempts to better understand young rabbit feeding behaviour are essential. Previous studies demonstrated the importance of diet presentation for growing rabbits, with a strong preference for pellets over alternative presentations (mash, raw materials, etc; Maertens, 2010). A recently published paper highlighted the influence of pellet diameter on the preferences of the suckling rabbit (Paës *et al.*, 2019). However, the feed properties that influence the young rabbit's voluntary feed intake before weaning remain largely unknown. The use of aromatic substances as additives seems promising to improve feed palatability since the rabbit's olfactory system is fully developed at birth (Gottlieb, 1971; Coureaud *et al.*, 2007 and 2008).

The first pellets consumed by young rabbits in commercial farms may not be adapted for grasping and chewing, and we hypothesised that other feed presentations may be more suitable for these young animals. In an attempt to stimulate early feed intake, we aimed to test (1) the suitability of different feed forms to encourage the creep intake and (2) the young rabbit's attraction for aromatic compounds before weaning. Throughout this paper, we use the term "creep feeding" to refer to the solid feeding of rabbit kits in the nest while they are still suckling. In the first trial, five feeds that differed by their presentation were provided in the nest with a single choice to determine their consumption by the young rabbit and to thus evaluate their acceptability. Dry presentations were tested with complete feed pellets, crumbled-pellets and crumbled beet pulp. Pieces of fresh beets and mashed beets included in a feed gel (semi-solid feed) were also provided. In the second trial, three commercial aromatic substances were included in a semi-solid feed form (agar gels) and provided in the nest following a double-choice experimental procedure to assess flavour preferences.

Material and methods

Animal housing and management

The study was conducted by the collaborative network of the Groupe d'Experimentation Cunicole (consortium of the companies CCPA, EVIALIS, INZO, MiXscience and TECHNIA). The experiments were carried out at the PECTOUL Experimental Unit (INRAE, Castanet-Tolosan, France). Female rabbits (hybrid breed PS19; Hypharm, France) were inseminated with semen from commercial male breeds for two consecutive reproductive cycles. The does and their litter ($n=60$ and 72 in Trials 1 and 2, respectively) were raised in a ventilated breeding unit in individual wire cages ($61 \times 69 \times 49$ cm, including the nest box: $38 \times 25 \times 20$ cm). Temperature varied between 16°C and 30°C (average temperature of 21°C and 20°C for the first and second trial). Cages were equipped to allow the mother and its litter to be separately fed (Paës *et al.*, 2019). The day of birth was designated as postnatal day 0 (0 day). At 2 days, nest quality was assessed using a 3-point scale: (1) corresponded to a nest of weak quality in which only wood shavings were found; (2) a nest of medium quality in which doe fur was present but insufficient to fully cover the litter and (3) a nest of good quality in which doe fur entirely covered the litter. After nest quality assessment, the litter size was standardised to ten kits per doe by cross-fostering or culling. Litters were assigned to treatments at 3 days by stratified randomisation on the does' parity (first to fifth parturition, three parities on average), the litter weight at standardisation (79 ± 9 and 69 ± 10 g/kit in Trials 1 and 2, respectively) and the allocation in the farm ($n=3$ rooms). Controlled suckling was applied once a day in the morning between 0800 h and 0900 h until 21 days. Two water nipples were available: one in the doe area and one in the litter space, outside of the nest. In both trials, feed was offered *ad libitum* to the young rabbits in the nest from 3 to 17 days using plastic cups (30 ml; height: 32 mm; diameter: 40 mm; GOSSELIN®, Le Mans, France). Cups present in the nest were removed before suckling to prevent the doe from eating in the nest, then weighed and finally reintroduced after suckling. The feed contained in the cups varied according to the experimental treatment. In both trials, all the litters received commercial pre-weaning pellets (P) *ad libitum* from 15 to 35 days in one feeder outside the nest, inaccessible to the doe. At weaning (35 days), kits were assigned to cages of five rabbits according to the experimental group before weaning and the litter of origin. Consistent with common feeding strategies in France, the animals were submitted to restricted feeding until 64 days in order to achieve an average daily gain of 40 g/day. Animals were then fed freely until slaughter (72 days).

Experimental groups and diets

In the first trial, 3 days after parturition, litters were divided into five experimental groups ($n=12$ per group) with one single choice of creep feed provided in the nest. In group P, kits received commercial pellets (length: 11 ± 3 mm,

Table 1 Ingredients of commercial pellets provided in the rabbit nest (Trial 1) and in the rabbit feeder (Trials 1 and 2), and chemical composition of the experimental feeds of the first trial. Commercial pellets (P), crumbled pellets (cP), sugar beet pulp pellet crumbs (cBP), raw fodder beetroots (B) and agar gels containing the pulp and juice of fodder beetroots (gB) were all provided in the rabbit nest

Ingredients (g/kg as fresh matter)				
	P and cP ^a			
Barley				174
Wheat bran				301
Rapeseed meal				30
Rapeseed oil				2
Sunflower whole seed				236
Sunflower husk				89
Sugar beet pulp				95
Sugar beet molasses				50
Sodium chloride				6
Calcium carbonate				12
L-Lysine, 20%				1
Mineral and vitamin premix ^b				5
Chemical composition (g/kg of fresh matter except for gross energy)				
	P and cP	cBP	B	gB
DM ^c	890	909	236	204
Gross energy (MJ/kg)	16.4	16.6	3.9	3.2
CP	172	82	9	9
Crude fat	27	2	2	1
Neutral detergent fibre	316	488	26	24
Acid detergent fibre	176	223	13	9
Acid detergent lignin	53	25	5	1
Ash	80	10	11	12
Starch	97	3	1	1

^aChemical analyses were performed on pellets (P) only, assuming that crumbles pellets (cP) have similar composition.

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

^cAt distribution.

diameter: 3.5 mm), formulated for rabbit females and their litter (Table 1). In groups cP and cBP, kits received crumbs from the same pellets P or crumbs from commercial sugar beet pulp pellets, respectively. To obtain the crumbs, pellets were ground with a rotor mill (Pulverisette 14; FRITSCH, Idar-Oberstein, Germany). Crumbs that passed through a 2.8-mm sieve but retained on a 2-mm sieve were used for the experiment. In the three groups (P, cP and cBP), feed was provided in a cup maintained horizontally in a holder to keep it in place while facilitating the daily handling for ingestion measures. Kits of the two other groups had access to hydrated feed onto a cup vertically clipped on one side of the nest. In all the cases, cups were placed at the nest material surface for better accessibility. Hydrated feed was either raw fodder beetroots (*Beta vulgaris* var. *crassa*) cut into cylinders to fit into the cups (treatment B), or agar gel feed poured into cups and obtained by mashing the fodder beetroots (gruel aspect, treatment gB). To prepare gels, fodder beetroot juice was extracted



Figure 1 Pictures illustrating alternatives to pellets provided in rabbit litter nests from 3 to 17 days. In the upper part of the figure: crumbled beet pulp pellets (cBP) and gels made with fodder beetroots (gB). In the bottom part of the figure: raw fodder beetroots (B).

and mixed with a part of the remaining pulp. The mixture was then heated to 80°C to allow the addition of agar (pulp-to-juice ratio of 1:4 with 0.2% of agar). The beetroot cylinders were cut and changed every 2 days, whereas the gels were renewed every day. Figure 1 illustrates the presentations of cBP, B and gB.

In the second trial, a double-choice feed preference test was conducted. All the feeds provided from 3 to 17 days were in the form of gels and differed only by the flavouring formulation incorporated. Gels contained either no aroma (labelled N), banana flavour (mix of flavouring substances 15% w/w on vegetal carrier, labelled B), red berry flavour (mix of flavouring substances 10% w/w on vegetal carrier, labelled R) or vanilla flavour (mix of flavouring substances 10% w/w on vegetal carrier, labelled V). The three sensory additives were provided by Phodé (Terssac, France). To produce feed gels, non-odorised commercial pellets were transformed into mash (particles size smaller than 2 mm), and the mash and the flavouring additive were then quickly mixed with hot water (80°C to 90°C) and agar (mash-to-water ratio of 1:4 with 0.6% of agar). Following the supplier's recommendations, flavours were incorporated at 0.20%, 0.06% and 0.10% for the B, R and V gel groups, respectively, in order to provide the same level of olfactory perception. The products and dosages are in compliance with regulation (EC) N° 1831/2003. The four types of gels were tested in pairs in two different cups vertically clipped onto the two opposite sides of the nest (height: 7.5 cm), which resulted in six experimental groups: BN, BR, BV, NR, NV and RV, where treatment

BN represents gel B tested against gel N for example ($n = 12$ litters per comparison group). To avoid confusion between feed location and flavour preference, the position of each kind of flavoured gel was reversed every day when the gels were renewed.

Chemical composition analysis was performed on creep feeds in the first trial using ISO methods (DM and ash for dry feed: ISO 6496:1999; nitrogen content: ISO 16634-1:2008; crude fat content: ISO 6492:1999; gross energy: ISO 9831:1998) and the procedures described by the European Group on Rabbit Nutrition (EGRAN, 2001). For hydrated feeds (B, gels gB, N, B, R and V), DM was obtained by freeze-drying for 48 h. Since the same commercial pellets P as those in the first trial were used to produce the feed gels in the second trial, only DM content was evaluated on these semi-solid feed (N: 243; B: 252; R: 259 and V: 253 g of DM/kg). The chemical composition of the experimental meals is given in Table 1. Hardness was determined 40 times with the Kahl Pellet Hardness Tester (AMANDUS KAHL GmbH & Co. KG, Reinbek, Germany) on pellets P (12 ± 3 kg force) and on the commercial sugar beet pulp pellets used to make up the cBP diet (66 ± 9 kg force).

Zootechnical measurements

Rabbit mortality was recorded daily from 3 to 72 days. Early feed intake was calculated daily at the litter level from 8 to 17 days in the first trial and from 10 to 17 days in the second trial using a 0.001-g accuracy scale. When waste or cup spillage occurred in one cup, we considered the daily feed consumption as missing data. In both trials, autogenic change in mass (water loss due to evaporation or moisture absorption) was evaluated for each type of feed in one empty nest per room from 8 to 17 days. The amounts of pellets offered in the feeders and refused were weighed at 15, 18, 21, 25, 28, 32 and 35 days. If one kit was found dead between these dates, the remaining feed in the cage was weighed to recalculate feed intake. Milk production was measured as the difference of female weight before and after suckling (Lebas, 1968; Maertens *et al.*, 2006) at 3, 7, 10, 14, 17 and 21 days. Litter weight after suckling was recorded at 3, 14, 21 and 28 days. Individual rabbit weight was measured at weaning, at 50 and 64 days.

Intake calculation and statistical analysis

Autogenic changes in the mass of pellets, crumbled-pellets and crumbled beet pulp were negligible (weight loss under the measurement uncertainty). Water loss was taken into account for raw beetroots and gel feeds intakes based on the evaporation measured in the controlled nests ($n = 3$ per room). In the first trial, a daily correction factor in grams was applied. For the gel feeds in the second trial, water loss amounted to 6% of the initial gel quantity supplied, regardless of the day and the experimental treatment. This correction was thus applied to the intake measurements. In the first trial, multiple imputations using predictive mean matching were performed (*mice* package in R software, R Core Team, 2018) on feed presentations with missing data in order

to calculate the total intake in the nest. Dietary intake and performance data before weaning (the litter as the experimental unit) were analysed by a one-way ANOVA followed by a post-hoc Tukey HSD test in the case of significant results. A linear mixed procedure was applied on post-weaning performance data (the rabbit as the experimental unit) with experimental group as a fixed effect and litter as a random effect. We modelled daily milk intake at 11, 12, 13, 15 and 16 days from data obtained in the farm with a quadratic model (Casado *et al.*, 2006). These longitudinal data were used in a linear mixed model aiming to investigate factors affecting feed gel consumption in the nest for the second trial. The notation of our model performed with *lmer* function in R software (R Core Team, 2018) was:

$$\text{Gel intake} \sim \text{Milk intake} + \text{Weight} + \text{Day} + \text{Nest} + (1|\text{Litter})$$

Gel intake: daily consumption of gel feeds by the litter; milk intake: daily consumption of milk by the litter; weight: litter weight at 3 days; day: between 10 and 17 days; nest: nest quality (on a 3-point scale).

To determine flavour preference in the second trial, relative consumption was calculated for each feed gel within a litter, which is the percentage contribution of one gel type to the total intake. For example, for a given litter of BN treatment, the relative consumption of gel B was calculated as follows:

$$\text{Relative consumption}_B = \frac{\text{Gel B intake}}{\text{Gel B intake} + \text{Gel N intake}} * 100$$

If the relative consumption value of a gel was significantly higher than the neutral value of 50% (sample *t*-test), then a preference for the given gel was considered within the treatment. When relative consumption values did not fit a normal distribution, arcsine transformation was used. All statistical analyses were performed using R software (R Core Team, 2018). Differences were considered to be significant when $P \leq 0.05$.

Results

Growth performance and health status

In the first trial, the mortality rates were 3.2% from 3 to 35 days and 1.6% from 36 to 72 days. They were not affected by the creep feed offered before weaning. In the second trial, mortality rates were 8.6% and 5.9% before and after weaning, respectively, and no experimental group effect on mortality was observed. In both trials, milk intake was similar between groups until 21 days. Similarly, the growth of the rabbits before and after weaning was not affected by the type of creep feed provided in the nest or by the sensory additives used (Table 2 and Supplementary Material Tables S1 and S2).

Table 2 Feed intake before weaning and live weight of 2- and 5-week-old rabbits according to the type of creep feed provided in the nest (Trial 1). Commercial pellets (P), crumbled pellets (cP), sugar beet pulp pellet crumbs (cBP), raw fodder beetroots (B) and agar gels containing the pulp and juice of fodder beetroots (gB) were all provided in the rabbit nest

	P	cP	cBP	B	gB	RMSE	P-values
n (litters)	12	12	12	12	11		
Total creep feed intake in the nest (g/rabbit) ¹							
Fresh matter	1.9 ± 0.5 ^c	0.8 ± 0.4 ^b	0.3 ± 0.1 ^a	1.0 ± 0.4 ^b	7.0 ± 1.8 ^d	0.8	***
DM	1.6 ± 0.4 ^b	0.7 ± 0.4 ^{ab}	0.3 ± 0.1 ^a	0.2 ± 0.1 ^a	1.4 ± 0.4 ^b	0.3	***
Commercial pellet intake in the feeder (g of DM/day/rabbit)							
15 – 18 ^d	0.2 ± 0.1	0.8 ± 0.8	0.5 ± 0.5	0.7 ± 0.8	1.2 ± 0.8	0.7	ns
18 – 21 ^d	3 ± 1 ^a	3 ± 1 ^a	4 ± 2 ^{ab}	4 ± 2 ^{ab}	5 ± 2 ^b	1.5	**
21 – 25 ^d	14 ± 3 ^a	14 ± 3 ^a	15 ± 3 ^{ab}	16 ± 3 ^{ab}	18 ± 3 ^b	3.1	*
25 – 32 ^d	44 ± 9 ^a	53 ± 6 ^b	55 ± 7 ^b	57 ± 15 ^b	56 ± 6 ^b	9.4	**
32 – 35 ^d	47 ± 13	53 ± 5	53 ± 8	54 ± 13	56 ± 6	9.6	ns
Cumulative pellet intake in the feeder (g of DM/rabbit)							
15 – 35 ^d	535 ± 58 ^a	536 ± 58 ^{ab}	560 ± 54 ^b	606 ± 180 ^b	593 ± 60 ^b	101	**
Live weight before weaning (g/rabbit)							
14 ^d	269 ± 25	268 ± 19	262 ± 21	255 ± 37	252 ± 26	26	ns
35 ^d	945 ± 106	930 ± 100	916 ± 104	922 ± 96	921 ± 99	101	ns

^{a,b,c,d}Means ± SD denoted by a different letter indicate significant differences between treatments ($P < 0.05$).

ns = $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

¹Calculated with imputed values when necessary with a maximum of three out of nine imputed values recorded per litter.

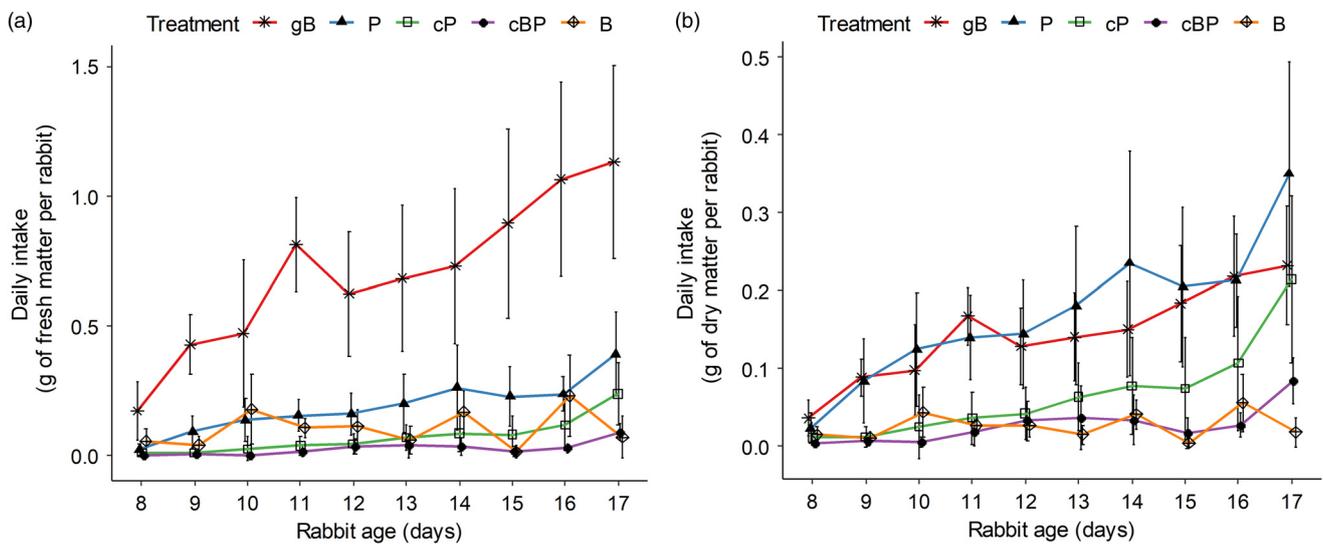


Figure 2 Kinetics of consumption of different creep feed types by young rabbits in fresh (a) or DM (b) (means ± SD, Trial 1). In the nest, in addition to doe milk, kits received commercial pellets (P), crumbled pellets (cP), crumbled beet pulp pellets (cBP), raw fodder beetroots (B) or gels made with fodder beetroots (gB).

Feed intake

Higher waste or cup spillage was observed for dry feeds: missing values accounted for 10%, 13%, 15%, 2% and 0% of consumption data, respectively, for P, cP, cBP, B and gB. Fresh matter and DM intakes in the nest were affected by the type of feed from the beginning of the first experiment (Figure 2 and Table 2). The daily intake of fresh gel gB was greater than the other creep feeds as of 8 days ($P < 0.001$). In fresh matter, the total feed intake of gB was 7 times higher than the intake of raw fodder beetroots B. The fresh intake of P feed was greater than the other dry feeds as of 9 days (0.1 g/rabbit, $P = 0.01$), and this difference was maintained throughout the experiment (+1.1 and +1.6 g of P feed fresh

matter consumed in the nest per rabbit compared to cP and cBP, respectively). The cBP feed was almost not consumed throughout the whole experiment (0.3 ± 0.1 g of fresh matter/rabbit in total). Regarding B presentation, a significant decrease in intake was observed the days the creep feed was not changed (–39%; $P < 0.001$) as for instance at 15 and 17 days in Figure 3. On a DM basis, total feed intake of gB and P were the highest ones (1.6 ± 0.4 and 1.4 ± 0.4 g/rabbit), and daily intakes were similar throughout the experiment, except at 17 days (+34% for pellets P compared to gB; $P = 0.03$). The type of creep feed provided in the nest appeared to have a subsequent effect on the intake in the feeder before weaning (Table 2). In particular, pellets consumption in the

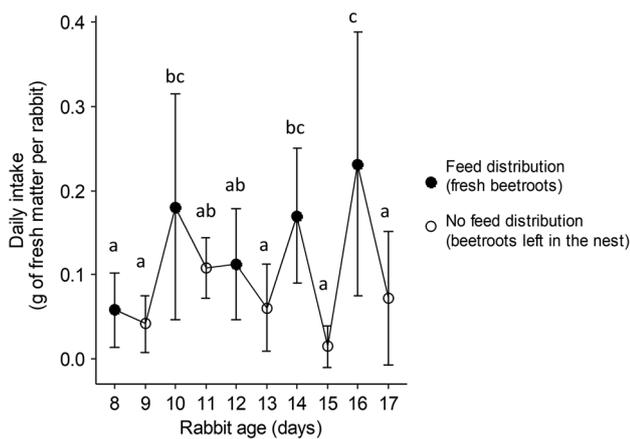


Figure 3 Intake pattern of raw fodder beetroots (B) provided in the rabbit nest from 8 to 17 days (Trial 1). On the day of distribution, beetroots were replaced by fresh ones and left in the nest for 2 days. Different letters indicate significant differences between days.

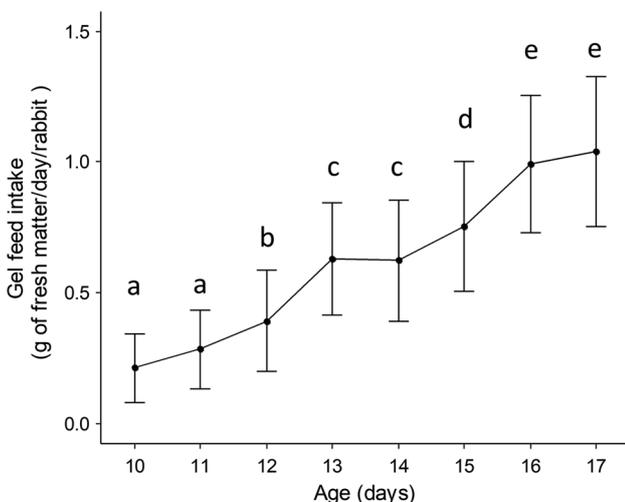


Figure 4 Kinetics of semi-solid creep feed intake by suckling rabbits, regardless of the flavour additive included (Trial 2). Means \pm SD denoted by different letters indicate significant differences between days.

feeder was significantly lower in the P group from 18 to 32 days than in the gB group (-18%).

In the second trial, over the period of 10 to 17 days, rabbits consumed a total of 5.0 ± 1.2 g of fresh gels in the nest/animal, which is equal to 1.2 ± 0.4 g of DM. In comparison, the gB intake in the first trial for a comparable period (10 to 17 days) was 1.3 ± 0.3 g of DM/rabbit and was not significantly different. The total intake in the nest, obtained by combining the intake of the two cups presented per cage, was similar between the six comparison groups (Figure 4 for the creep feed intake kinetics regardless of the treatments). Within each treatment, we observed that relative consumption of gels containing vanilla aroma was greater than 50% when presented against gel B ($56 \pm 7\%$; $P=0.03$), gel N ($57 \pm 9\%$; $P=0.001$) and gel R ($58 \pm 7\%$; $P=0.006$), meaning that a preference was expressed for vanilla flavour (Figure 5). No other preference was expressed in the nest

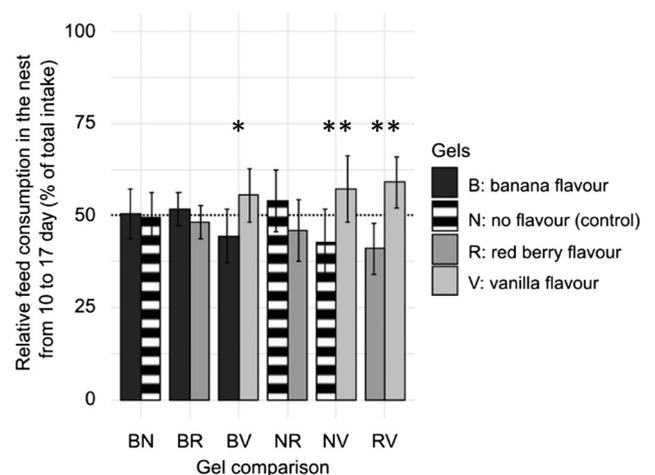


Figure 5 Relative consumption of experimental gels from 10 to 17 days (Trial 2). In the nest, rabbit kits had the choice between two gels that differed in flavour (N: no flavour, B: banana flavour, R: red berry flavour, V: vanilla flavour). For a flavour in a given comparison treatment, a relative consumption value significantly superior to 50% is understood as the expression of a preference. Results are presented as means \pm SD.

within treatments. The pellet intake in the feeder did not differ between the groups in this second trial.

We analysed the factors influencing the early feed intake (10 to 17 days) in the second trial to study between-litter variability of creep feed intake. We found that daily milk intake did not affect the corresponding daily solid feed intake. Similarly, total milk intake throughout this period and nest quality had no significant effect on the total creep feed intake (Figure 6). Instead, the litter weight at 3 days of age (average BW at 3 days: 95 ± 11 g/rabbit) influenced the daily creep feed intake ($P < 0.001$) and was positively correlated with the total creep feed consumption ($r=0.40$; $P < 0.001$, Figure 6). Gel feed intake started on average at 10 days for the heaviest litters (100 to 121 g/rabbit at 3 days) and one day later for the lightest ones (66 to 91 g/rabbit at 3 days; $P=0.03$). Similarly, the litters that started to consume creep feed at 10 days ($n=38$ litters, 55% of the flock) were significantly heavier at equalisation ($+8$ g of BW/rabbit; $P=0.04$) than litters that ingested feed at 12, 13 or 14 d ($n=16$ litters, 23% of the flock).

Discussion

In commercial rabbitries, kits only have access to solid feed when they are able to move to the doe's feeder, generally from 16 to 18 days. Yet, previous studies demonstrated that the onset of solid intake can occur prior these ages when early access to a substrate was provided (feces: Kovács *et al.*, 2006; Combes *et al.*, 2014; feed: Kacsala *et al.*, 2018; Paës *et al.*, 2019). In mammals, digestive health is under control of gut microbiota (Fortun-Lamothe and Boullier, 2007). Considering that introduction of solid feed in the diet is a major regulator of microbiota implantation (Bian *et al.*, 2016; Read *et al.*, 2019), we assumed that solid

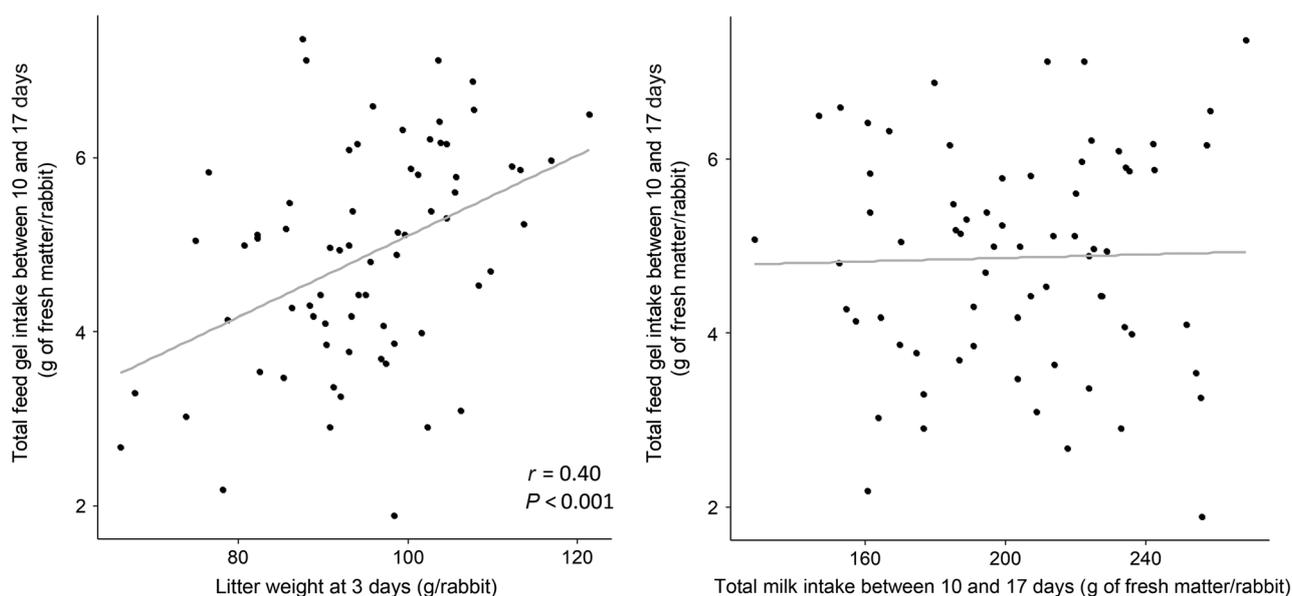


Figure 6 Early feed intake according to the rabbit litter weight at the beginning of the experiment (3 days) and the milk intake, regardless of the experimental treatments ($N=69$ litters, Trial 2). On the left: the relationship between the total feed gel intake in the nest and the litter weight at 3 days. On the right: the relationship between the total feed gel intake and the corresponding total milk intake.

feed ingestion at an early stage should be promoted since it may exert positive effects on rabbit's development. In this regard, the aim of this study was to obtain insight into the acceptability of feed presentations and flavour preferences in order to propose tools for promoting early feed intake. To our knowledge, this study provides never published information about non-pelleted feed presentations dedicated to suckling rabbits. We confirmed in the first trial that suckling rabbit was able to consume solid feed as early as 8 days. Higher intakes in fresh matter were observed with gel presentation, while preferences for vanilla aromatic compound were detected in the three situations it was provided.

In the first trial, the objective was to compare creep feeds that differed by their presentation alone. For technical reasons, the feed types (e.g., complete feed, sugar and fodder beets) differed between the creep meals tested, which can influence the intake, in addition to the effects of feed shape and texture. However, it was hoped that these confusing effects could be avoided by comparing diets that shared the same main ingredients such as pellet vs. crumbled pellet and raw fodder beet vs. fodder beet gel. The onset of solid feed intake was stimulated with pellets compared to crumbled pellets. As far as we know, no previous studies investigated the use of crumbled feed in rabbit production. Crumbs between 2 and 2.8 mm may be less well adapted to the rabbit's grasping than the pellets tested. Early intake increased by 86% with the beet gel compared to the corresponding raw materials. Since hardness is known to affect rabbit feeding behaviour (Maertens, 2010), this better acceptability could be explained by the softness of the gel-type feed. The pellets used to produce beetroot crumbs were six times harder than the complete feed pellets, which could also explain the low intake of beetroot crumbs compared with complete feed crumbs. In addition to hardness, the feed

presentation attractiveness seemed to be affected by its freshness since the raw beetroot intake varied greatly from day to day, showing fluctuations according to its DM content. This unexpected freshness effect suggests that the kits' intake is partly driven by thirst. This could explain why fresh chicory (*Chicorium intybus L.*) was found to be attractive at a very early age in young rabbits (DM: 5%; Castellini *et al.*, 2007) as well as fresh young grass stalks as of 13 days (Langenbach *et al.*, 2001). Knowing that the kit cannot access water before it is able to leave the nest, these observations support the idea that the water requirements of young rabbits may not be met in commercial conditions.

Among all the creep feed tried, the feed gel seems interesting since it induced the highest intake of fresh matter and a significant dry intake occurred at an early stage. Benefits of diets in gruel form for piglets management were summarised by Brooks and Tsourgiannis (2003): a liquid diet provides a DM content similar to that of sow's milk, which encourages intake, satisfies young pigs' needs for nutrients and water and eliminates the problem for piglets of learning to satisfy hunger and thirst separately. In our experiment, DM of beetroot feed gel (20%) was close to that of doe's milk (30% expected according to Maertens *et al.*, 2006). As for pigs, it could be hypothesized that gel consumption partly "mimics" milk feeding, making gels attractive to kits. However, detailed monitoring of the kits behaviour is necessary to evidence this assumption. Moreover, this feed form might be more adapted to young rabbits, whose mastication is not fully functional at 13 days (Langenbach *et al.*, 2001; Coureaud *et al.*, 2008) since it does not require being crushed. However, one limitation of this gel presentation for a putative commercial use is the time-consuming aspect of the preparation. Consequently, some technical adaptations should be further developed. Contrary to what we

previously thought, classical pellets (length: 11 mm; ϕ : 3.5 mm) were also adequate to feed rabbit kits since they showed significant intake as of 9 days and high total intake values in DM.

It is interesting to note that when creep feed was proposed in the nest, it had some effect on pellet intake several days later, that is, a few days before weaning. Animals receiving pellets in the nest seemed to delay the intake of the same pellets provided outside of the nest, which, however, did not affect their growth. Maertens (1994) noted that a switch of pellet diameters at weaning (ϕ 2.5 mm followed by 4.8 mm) increased the intake and the daily weight gain compared to a stable pellet presentation (ϕ 4.8 mm before and after weaning). In our study, when the feed presentation changed from hydrated form to pellet, higher feed intake was observed compared to the situation where pellets were provided constantly through the pre-weaning period. Further investigations are necessary to confirm if a change in feed presentation before weaning can increase its attractiveness. Our results also highlighted the fact that milk consumption was not disturbed by the creep feed intake until 21 days (last milking measurement). This does not support the hypothesis of Kacsala *et al.* (2018) who proposed that early solid feeding of young rabbits could reduce the 'pressure' on the doe for milk production and delivery.

Given the attractiveness of the gel and its ease of use for intake measurements (no waste or cup spillage), we continued the study using the gel texture by incorporating mash pellets and different aromas. Data suggest that the vanilla flavour tested in the current study conditions improved the semi-solid creep feed palatability in early stages of the suckling period. The interest of flavour additives on feed palatability and intake for rabbits has been previously described, for example, with thyme during the rabbit fattening period (Fekete and Lebas, 1983), but to our knowledge, the present results are the first to highlight the potential interest of vanilla flavour. An effective way to contribute to vanilla attractiveness could be to add the aromatic component in the doe's diet since it can promote kits preferences for it (Bilkó *et al.*, 1994). This phenomenon can be explained by the perinatal chemical continuity induced by certain aromas contained in the doe's diet, which are both present and detected by the foetus and then the neonate in the amniotic fluid and in the colostrum (Schaal *et al.*, 1998; Coureaud *et al.*, 2002; Guiraudie-Capraz *et al.*, 2005). We are aware that attractiveness was evaluated here at the litter and not at the individual level, and it might therefore be subject to wide inter-individual variability such as that described for juvenile pigs exposed to different sensory ingredients (Clouard *et al.*, 2012). It also has to be underlined that the preference for vanilla remained moderate in our conditions, and that despite this preference, the total intake in the nest of litters receiving vanilla gel was similar to other groups. As suggested by Lebas (2011) who tested increasing incorporation of formaldehyde in rabbit diets, the nutritional value of the feed seems to be the major driver of the rabbit ingestion, rather than the sensory experience, except in the case of

clear-cut aversion. Thus, further experiments must be done to determine preferences for vanilla at the individual level and its putative use to consistently favour solid feed consumption in the nest.

Finally, this study underlines the effects of animal-related factors on the onset of solid feed intake. Whereas it has been demonstrated that solid intake between 16 and 25 days depends on the milk availability (Fortun-Lamothe and Gidenne, 2000), the creep feed consumption was independent of the milk intake between 10 and 17 days at the litter level. The lack of correlation between creep feed intake and the corresponding milk intake corroborates with the study of Paës *et al.* (2019), performed with similar methods. These results are likely explained by the early period studied where the feed-seeking behaviour of the kits is limited. In this study, litter weight after standardisation affected, on the one hand, the amounts of creep feed ingested and, on the other, the date at which solid feed intake began. Increased solid intake was found for the heaviest rabbits, as previously shown by Pajor *et al.* (1991) at the within-litter level in suckling piglets. The superior intake of heavy rabbits could be explained by higher mobility or greater nutrients needs, as well as digestive systems with greater degrees of maturity in terms of enzymatic activity and digestive tract size (de Passillé *et al.*, 1989). Further studies are now required to determine the non-dietary factors that may affect the suckling rabbit's willingness to eat creep feed.

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Declaration of interest

None

Ethics statement

The experiments were carried out at the PECTOUL Experimental Unit (INRAE, Castanet-Tolosan, France, agreement B31 113 16). Animals were handled according to the guidelines for animals used in experiments, according to EU 2010/63/EU and in agreement with French legislation (NOR:AGRG1238753A 2013).

Software and data repository resources

None of the data were deposited in an official repository.

Supplementary material

To view supplementary material for this article, please visit <https://doi.org/10.1017/S1751731120000038>

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