Impact of feed intake level and feeding time on some digestive parameters of the growing rabbit

*Tese de Mestrado*

Engenharia Zootécnica

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Aos meus Pais.
“As doutrinas apresentadas no presente trabalho são da exclusiva responsabilidade do autor”
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Preface

I am a student at the University of Trás-os-Montes and Alto Douro located in Vila Real, Portugal, where I am doing a master degree in Animal Science.

I developed a research project based in Rabbit Sciences at UMR 1289 TANDEM, located at the INRA-Toulouse Research Centre (France). This project mainly intended to contribute to clarify the effects of the level of the feed restriction (restricted vs. *ad libitum* feed intake) and time for access to the feeder (free vs. limited access to the feeder) on the growing performances and whole tract digestibility (i.e. apparent faecal digestibility) of the feed in the growing rabbit. Indeed, due to the wider context of INRA-Toulouse rabbit research, it is of the general interest of all the scientific community interested in Rabbit sciences as well as for the rabbit farmers to know more about this topic, to optimise the productivity of their animals, i.e. reducing feeding costs and reducing losses of animal.

This report is divided in four main parts: an introduction, where the purposes of the above mentioned study are explained; a second part, where some of the current theory about the topic is described; a third part, where the methodology used is described and the results obtained are presented and discussed, respectively; a fourth and last part, where the final conclusions withdrew of the project are presented.
Summary

After weaning, a feed restriction may be recommended in order to prevent post-weaning digestive disorders of the growing rabbit. The main aim of this project was to study the effect of the level of feed restriction and time for access to the feeder on the digestive process of the growing rabbit.

The experiment was designed according to a 2×2 factorial model, where four groups of 12 rabbits were allotted to compare the effects of the intake level (ad libitum or limited to 75% of the ad libitum) and time for access to the feeder (free access to feeder 24h/24 or access denied between 10h30 and 16h30). These treatments were applied between 32 and 63 days old, and between 63 and 70d old the animals were fed ad libitum with free access to feeder. In this trial the following measurements were made: diet digestibility, growth, feed intake, health status and faecal excretion rhythm.

Whatever the parameter, no significant interactions among the intake level and the time for access to the feeder were found. During the restriction period (32-63 days), the reduction of the intake level led to a proportional reduction of the live weight (-18%, P<0.001), while there was no significant effect of the time for access to the feeder whatever the age of the animals. The daily weight gain was also proportionally reduced (-26.8%, P<0.001) according to the reduction of the level of feed intake. During the ad libitum period (63-70 days), the restricted animals exhibited an important compensatory growth (+66%, P<0.001), associated to a higher intake (+8.5%, P<0.01). The time for access to the feeder did not significantly affect the weight gain or feed intake. While during the restriction period, the reduction of the intake level did not affect the feed conversion, reversely, during the realimentation (63-70 days), the feed conversion of restricted rabbits was greatly improved.

The level of feed restriction has a favourable significant effect on feed digestibility during the restriction period, whatever the nutrient. The faecal digestibility of organic matter and ADF was about 3 units higher, while for crude protein this effect was greater (+6 units). Respect to the time for access to the feeder, with the exception of the digestibility of the NDF and hemicelluloses that
was higher in the animals with limited access to the feed, the digestibility of all the other components was not modified significantly.

A low level of intake resulted in an earlier hour for faecal excretion (7h-19h), being this one more significant during the morning and less important during night. When the access to the feeder was denied (10h30-16h30), a two-phase excretion pattern (7h-13h and 15h-21h) was observed for animals having as well a reduced intake level. In addition, a reduced time for access to the feeder led to a more important faecal excretion during night and less important during the morning.
Resumo

A aplicação de uma restrição alimentar após o desmame, é recomendada por alguns autores para prevenir a ocorrência de doenças digestivas, cuja incidência é maior em coelhos após o desmame. O principal objectivo deste trabalho foi estudar o efeito do nível de restrição alimentar e do tempo de acesso ao alimentador em alguns parâmetros digestivos do coelho em crescimento.

A experiência foi delineada de acordo com um modelo factorial 2×2, onde 4 grupos de doze coelhos com 32 dias de idade foram distribuídos ao acaso, de forma a comparar os efeitos do nível de ingestão de alimento (ad libitum vs. 75% do nível ad libitum) e do tempo de acesso ao alimentador (acesso livre ao alimentador 24h/24 ou acesso não permitido entre as 10h30 e as 16h30). Este maneio foi realizado entre os 32 e os 63 dias de idade e entre os 63 e os 70 dias de idade (abate), todos os animais foram alimentados ad libitum e com livre acesso ao alimentador durante todo o dia. A digestibilidade da dieta, o crescimento dos animais, a ingestão de alimento, o estado sanitário e o ritmo de excreção fecal foram as determinações realizadas neste trabalho.

Nos resultados obtidos, não foram encontradas interacções significativas entre o nível de ingestão e o tempo de acesso ao alimentador, para qualquer dos parâmetros avaliados.

Durante o período de restrição (32-63 dias), uma redução da ingestão de alimento levou a uma redução proporcional do peso vivo animal (-18%, P<0.001). Por outro lado, o tempo de acesso ao alimentador não teve qualquer efeito no mesmo parâmetro. O ganho de peso diário dos coelhos sujeitos a uma menor ingestão sofreu também uma forte redução (-26.8%, P<0.001).

Durante o período ad libitum (63-70 dias), os animais anteriormente sujeitos a uma menor ingestão apresentaram um importante fenómeno de crescimento compensatório (+66%, P<0.001), associado a uma maior ingestão de alimento (+8.5%, P<0.01) destes animais durante este período. O tempo de acesso ao alimentador não teve qualquer efeito no ganho de peso ou na ingestão de alimento.
Durante o período de restrição, o índice de conversão alimentar não foi afectado significativamente pelos tratamentos em questão. Contudo, durante o período seguinte (alimentação *ad libitum*) nos animais anteriormente restringidos, este melhorou significativamente.

Durante o período de restrição alimentar foi observado um efeito positivo do nível de ingestão na digestibilidade do alimento, qualquer que seja o nutriente em causa. Observamos que a digestibilidade fecal da matéria orgânica e do ADF foi maior cerca de 3 unidades, enquanto que, a digestibilidade da proteína bruta foi ainda maior (+6 unidades). No que diz respeito ao tempo de acesso ao alimentador, com a excepção da digestibilidade do NDF e da hemicelulose, que foi maior em animais com menor tempo de acesso ao alimento, a digestibilidade de todos os outros componentes não foi alterada.

No ensaio foi também possível observar que, um reduzido nível ingestão provoca uma antecipação do período de excreção fecal (7h-19h), sendo este mais significativo durante a manhã e menos importante durante a noite. Quando o acesso ao alimentador não era permitido (10h30-16h30), observou-se uma dupla fase de excreção fecal (7h-13h e 15h-21h) em animais estando simultaneamente sujeitos a um reduzido nível de ingestão. Além disso, foi possível observar que animais com menor tempo de acesso ao alimentador apresentaram um ritmo de excreção fecal mais importante durante a noite e menos importante durante a manhã.
Résumé

Le rationnement alimentaire est souvent utilisé en élevage cunicole afin de prévenir l’apparition des troubles digestifs post-sevrage. Le principal objectif de ce travail a été d’étudier les effets du niveau du rationnement et du temps d’accès à la mangeoire dans le procès digestif du lapin en engraissement.

Le dispositif expérimental consiste en un modèle bi factoriel à 2×2 niveaux, où 4 groupes de 12 lapins ont été groupés pour comparer les effets du niveau d’alimentation (ad libitum vs 75% du niveau ad libitum) et du temps d’accès à la mangeoire (accès libre à la mangeoire 24h/24 vs accès restreint entre le 10h30 et 16h30). Ce schéma a été appliqué entre 32 et 63 jours d’âge, avec un retour à l’alimentation à volonté et accès libre à la mangeoire de 63 jours jusqu’à 70 jours d’âge. Dans cet essai, nous avons contrôlé la digestibilité de la diète, l’ingestion d’aliment, croissance, l’état sanitaire et le rythme d’excréption fécale.

Il n’y a pas d’interactions significatives entre les deux facteurs principaux (niveau de rationnement et temps d’accès à la mangeoire), pour aucun des paramètres étudiés. En période de restriction (de 35 à 63 jours d’âge), la réduction de l’ingestion entraîne une réduction proportionnelle du poids vif (-18%, P<0.001), tandis qu’il n’y a pas eu d’effet significatif du temps d’accès à la mangeoire quelle que soit l’âge des animaux. Le gain moyen quotidien a été aussi proportionnellement réduit selon la réduction du niveau d’ingestion (-26.8%, P<0.001). Le retour à l’alimentation à volonté (63 à 70 jours) entraîne une forte croissance compensatrice (+66%, P<0.001), associée à l’accroissement de l’ingestion (+8.5%, P<0.01). L’effet du temps d’accès à la mangeoire n’a pas d’effet significatif, que ce soit sur l’ingestion ou le gain moyen quotidien. Pendant la période de rationnement, la diminution du niveau d’ingestion n’a pas affecté l’indice de consommation, alors que, pendant la période de réalimentation (63-70 jours), l’indice de consommation des lapins rationnés a été très amélioré.

Le niveau d’alimentation a eu un effet significatif favorable dans la digestibilité de la diète pendant la période de rationnement, quelle soit le nutriment. La digestibilité fécale de la matière organique et de l’ADF a été 3 unités plus élevée et encore plus élevée pour la protéine brute (+6
unités). En ce qui concerne le temps d'accès à la mangeoire, à l'exception de la digestibilité du NDF et hémicelluloses qu'a été plus élevée chez les animaux avec un accès limité à la mangeoire, la digestibilité de tous les autres nutriments n'a pas été modifiée de façon significative.

Dans cet essai, nous avons aussi observé qu'un faible niveau de consommation a abouti à une excrétion fécale plus précoce (7h – 19h), celle-ci étant plus importante pendant la matinée et moins importante pendant la nuit. Quand l'accès à la mangeoire était interdite (10h30-16h30), un modèle d'excrétion à deux phases a été observé pour des animaux ayant aussi un niveau de consommation réduit. De plus, un temps réduit pour l'accès à la mangeoire a mené à une excrétion fécale plus importante pendant la nuit et moins importante pendant la journée.
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I. Introduction

In the last years, there has been an increased interest in studying feed restriction in rabbits (Tumova et al., 2004; Yakubu et al., 2007). Feed restriction has been studied in order to improve biological and economic performance (Tumova et al., 2006), i.e. as a means of reducing the costs of production (Yakubu et al., 2007).

In the rabbit, an early feed restriction, applied from post-weaning age can be of interest to reduce post weaning digestive disorders (Gidenne et al., 2003; Boisot et al., 2004; Ben Rayana et al., 2008a), namely the Epizootic Rabbit Enteropathy syndrome (ERE) (Boisot et al., 2003; Gidenne et al., 2003; Tudela et al., 2006). In fact, digestive disorders are the main cause of morbidity and mortality in growing rabbits and are those which are responsible for important economic losses in industrial rabbit farms (Licois, 2004).

Besides, a feed restriction can also be of interest in many other aspects of growing rabbits, namely:

- improves feed efficiency (Perrier and Ouhayoun, 1996; Tumova et al., 2002; Boisot et al., 2003; Gidenne et al., 2003; Dalle Zotte et al., 2005; Yakubu et al., 2007; Bergaoui et al., 2008),
- reduces carcass fat deposition (Ledin, 1984, 1984a, 1984b; Perrier, 1998; Boisot et al., 2004; Tumova et al., 2004; Bergaoui et al., 2008),
- induces compensatory growth (Ledin, 1984; Perrier, 1988; Perrier and Ouhayoun, 1996; Tumova et al., 2002; Boisot et al., 2003; Gidenne et al., 2003; Dalle Zotte et al., 2004, 2005; Foubert et al., 2007, 2008 ; Matics et al., 2008) ,
- improves digestibility of nutrients during the restricted feeding period (Ledin, 1984, 1984b; Xicatto and Cinotto, 1988; Xicatto, et al., 1992, 1992, Gidenne, 1993; Diaz Arca et al., 1999; Turnova et al., 2004; Di Meo et al., 2007).

Nevertheless, besides all the studies already made concerning this subject, actually, to give reliable recommendations about the level and restriction technique, further studies are needed to
determine the consequences of a quantitative feed restriction on the digestion of the growing rabbit. Therefore, the main aim of this project was to contribute to clarify the effects of the level of the feed restriction (restricted feeding regime vs. total *ad libitum* feed intake) and the time for access to the feeder (free vs. limited access to the feeder) on the digestibility of a feed in the growing rabbit.
II. Literature review

1. The digestion in the rabbit

1.1. Digestive tract anatomy

The rabbit is an herbivorous that presents a particular digestive physiology. Indeed, these animals ingest a large amount of feed, make a lot of meals per day (20 to 30), have a fast digestive transit, possess significant caecal fermentation and have the ability to practise caecotrophy (Pinheiro, 2002). The general organisation of the rabbit tract is presented in the figure 1.

![Digestive tract of the rabbit](image)

Figure 1: The digestive tract of the rabbit. Numerical values are those observed in a 2.5 kg New Zealand White rabbit, fed ad-libitum, a pelleted balanced diet (Lebas, 2002; Forthun-Lamothe and Gidenne, 2006)
1.1.1. The mouth

The rabbit possesses 6 molars and 2 pairs of incisive teeth (Feugier, 2002). However, this animal doesn’t have canines and pre-molars. The salivary glands (parotid, mandibular, sublingual and zygomatic) produce saliva that has a low content in amylase (25 μMoles of maltose per mg of salivary protein produced as a result of the starch degradation, against 250-450 produced by the pancreatic juice) (Lebas, 2002; Feugier, 2002).

1.1.2. The oesophagus

The oesophagus is located between the trachea and the spinal column. It only allows the movement of the alimentary bolus in the direction of the stomach. There is never backward flow of the alimentary bolus from the stomach towards the mouth, even in an accidental way (Lebas, 2002).

1.1.3. The stomach

The stomach is the first important compartment of the digestive system of the rabbit (Carabãno and Piquer, 1998) and it constitutes a first storage cavity for the feed. The stomach is divided into two different parts, fundus and antrum (Feugier, 2002). The initial extremity of the stomach is denominated cardia and its wall excretes a gastric lipase, which production reaches its maximum when the animal has 30 days of age. On the other hand, the terminal extremity is delimited by the pylorus that due to its contractions regulates the passage of the food portions into the duodenum (Feugier, 2002).

The environment of the stomach is acid (pH ranges from 1 to 5) (Carabãno and Piquer, 1998) due to the secretion of hydrochloric acid by the parietal glands. Besides the hydrochloric acid, the parietal glands also produce pepsin and rennin or chymosin that is an endopeptidase responsible for the milk and minerals (Ca, K, Mg and Na) coagulation in the stomach, that is imperceptible in the stomach of a rabbit after the 45 days of age (Lebas, 2002; Feugier, 2002).
1.1.4. The small intestine

The small intestine is divided in three main regions: duodenum, jejunum and ileum. The ductus choledochus that transports the bile from the liver ends in the beginning of the duodenum. Its opening to the duodenum is regulated by the Oddi’s sphincter. It is important to refer that, in the rabbit, the bile is secreted almost in a permanent way by the liver and stocked in the gall-bladder just after being released. Reversely, the pancreatic channel ends in the last part of the duodenum, at around 40 centimetres of pylorus.

The pH of this organ in its first part is slightly alkaline (pH 7.2-7.5), however in the last part of the ileum it reaches a pH value of 6.2-6.5 (Lebas, 2002).

1.1.5. The caecum

The caecum constitutes a second store where the feed is stocked (Lebas 2002; Feugier, 2002). It has a form of a spiral that increases the mucosa surface that is in contact with the caecal content (Feugier, 2002). The pH of the caecal contents is slightly acid (5.6-6.2). Its capacity is approximately 49% of the total capacity of the digestive tract (Carabâno and Piquer, 1998).

The caecum is characterised by the presence of microbial activity which assumes a significant role on the digestion since the rabbit’s fourth week of life (Feugier, 2002). The main genus of the microbial population in the caecum of the rabbit is Bacteroides. These bacteria can have cellulolytic, pectinolytic, xylanolytic, proteolytic, amylolytic and ureolytic activity (Carabâno and Piquer, 1998; Feugier, 2002).

1.1.6. The colon

The colon can be divided in two parts (Feugier, 2002), proximal and distal (Carabâno and Piquer, 1998). The colon also possess a flora, however less numerous than the one present in the caecum. The proximal colon is responsible for the flux of hard and soft faeces (i.e. caecotrophes)
as the rabbit is characterised by the excretion of two different types of faeces, soft and hard with different chemical compositions (Feugier, 2002).

1.2. The digestive physiology

The digestive process starts in the mouth with the prehension of the feed, in which the 2 pairs of incisive teeth play an important role. The saliva’s action will just be exerted in the stomach due to the high rate of passage of the feed in the mouth (Feugier, 2002). After the mouth, the feed passes through the oesophagus in the direction of the stomach (Feugier, 2002).

The feed is stored temporarily in the stomach (Feugier, 2002) remaining there 2 to 4 hours (Lebas, 2002). The enzymatic digestion starts in the stomach with the action of the pepsin in the proteins. After that, and due to the powerful stomachic contractions (Lebas, 2002), the alimentary bolus reaches the small intestine.

The small intestine has an important role because it modifies in a considerable way the composition of the feed that entry in the caecum (Feugier, 2002). Once in the small intestine, the alimentary bolus is diluted by the action of the bile, the first intestinal secretions and finally by the pancreatic juice (Lebas, 2002). The enzymes present in the pancreatic juice are responsible by the enzymatic degradation of the feed. They have the ability to degrade the sucrose (saccharose), starch, triglycerides and the majority of the proteins. The bile excreted by the ductus choledochus in the beginning of the duodenum has the capacity of emulsify the fat in a stable way, in order to facilitate their digestion. The numerous parietal glands present in the small intestine excrete other enzymes that complete the activity of the enzymes excreted in the pancreas (Feugier, 2002).

After this process, the elements easily degradable (which digestion was completed in the small intestine) are released, cross the intestinal wall and are distributed in the cells under the blood action (Lebas, 2002). However, one part of the feed is not degraded at this level, namely the fibres, the parietal carbohydrates (cellulose, hemicelluloses and lignin) and oligosaccharides (Feugier, 2002). Thus, these non degradable elements, after a total remaining time of
approximately 1 hour and 30 minutes in the small intestine, enter the caecum where they will remain during 2 to 12 hours (Lebas, 2002).

![Digestive mechanism in the rabbit (Lebas, 2002)](image)

**Figure 2: Digestive mechanism in the rabbit (Lebas, 2002)**

The caecum is the unique place in the digestive system of the rabbit where occurs fibre degradation and fermentation (Feugier, 2002) due to the existence of microbial activity. As a result of these processes are produced hydrogen, methane and carbon dioxide (result of the fermentation of simple sugars and amino acids), ammoniac (fermentation of amino acids) and volatile fatty acids (60-80 moles of acetate, 8-20 moles of butyrate and 3-10 moles of propionate per 100 moles of volatile fatty acids) (Feugier, 2002). However, the volatile fatty acids' proportion changes with the time of the day (namely, after a meal) and with the developmental stage of the
rabbit: increases in the acetate’s concentration from 15 to 25 days of age and reversal of the propionate to butyrate ratio from 15 to 29 days of age (Carabâno and Piquer, 1998).

The products resultant of the degradation process occurred in the caecum are released, cross the intestinal wall and are transported through the blood till the cells. The other caecum contents (half constituted by the large and small food particles not degraded before, and other half constituted by the body of bacteria developed in the caecum and the rests of digestive secretions coming from the small intestine) in its turn are evacuated towards the colon (Lebas, 2002).

In the ruminants, the feed is first fermented in the rumen, and then reaches the small intestine. In the rabbit, the process is at the opposite: first the digesta goes to the stomach and small intestine, and then is fermented in the caecum and proximal colon (Feugier, 2002).

The functioning of the rabbit’s upper digestive tract is globally the same as that of other monogastric domestic mammals. Specificity of the rabbit (and Lagomorpha in general) lies in the dual function of the proximal colon. If the caecum contents enter the colon in the early part of the morning they undergo few biochemical changes. The colon wall secretes mucus, which gradually envelops the pellets formed by the wall contraction. These pellets gather in elongated clusters and are called soft faeces (i.e., caecotrophes). If the caecal digesta enter the colon at another time of the day, the activity of the proximal colon is entirely different. Successive waves of contractions in alternating directions (Forthun-Lamothe and Gidenne, 2006), also named as antagonist contractions (peristaltic and anti-peristaltic) (Feugier, 2002), begin to act (figure 3); the first to evacuate the contents normally and the second to push them back into the caecum. Most of the liquid fraction (soluble products and small particles with a diameter lower than 0.1mm) is forced back into the caecum (Lebas, 2002; Forthun-Lamothe and Gidenne, 2006). The solid part, containing mainly large particles over 0.3 mm long, forms hard faeces. This dual action of the colon produces two types of faeces: hard and soft, the later is richer in protein (half of bacterial origin) and water vitamins (B and C). While hard faeces are excreted, the soft ones are ingested by the rabbit directly upon being expelled from the anus (Lebas, 2002; Forthun-Lamothe and Gidenne, 2006), without masticate it (Feugier, 2002).
1.3. Caecotrophy

Caecotrophy must not be confounded with the coprophagy (when animals have only one type of excrement), since it is an herbivorous strategy to benefit from the microbial protein (Fortun-Lamothe and Gidenne, 2006). In fact, the caecotrophy contributes more to the digestion of protein that of fibres. According to the type of feed and animal, this phenomenon can represent 5-30% of the intake of digestible energy, 7-26% of the dry matter intake, 11-55% of protein intake, 17% of the sulphured amino acids intake, 18% of lysine and 21% of the treonin. The nutritional importance of the caecotrophy varies according with the nutritional characteristics of the diet, having a more important role in diets with a low content in energy (Pinheiro, 2002).

![Diagram of digestive system](Gidenne, 1996)

**Figure 3: Movement of digesta in the rabbit ileo-caeco-colic segment**

1. liquids and fine particles;
2. large particles (>300μm); 3. peristaltic digesta movement; 4. antiperistaltic digesta movement

(Gidenne, 1996)
Soft faeces are excreted according to a circadian rhythm which is the opposite of that of feed intake and hard faeces excretion. Caecotrophy occurs mainly at the beginning of the light period, whereas feed intake and hard faeces excretion occur preferentially during darkness. The age of the rabbits, their physiological status or restricted access to the feed can alter this pattern. (Carabâno and Piquer, 1998).

According to Carabâno and Piquer (1998), weaned rabbits (6 weeks old) show a greater incidence of dysphasic patterns and a longer caecotrophy period than adults (14 weeks old) from 4h to 12h and to 22h to 24h and from 22h to 24h vs. from 8h to 14h, respectively.

During the lactation period, does exhibit an alternated rhythm of soft and hard faeces excretion. Caecotrophy occurs during two periods from 2h to 9h (0.40 of total excretion) and from 13h00 to 17h00 (0.60 of total excretion), with a lack of excretion from 9h to 13h (Carabâno and Piquer, 1998).

When the feeding regime is changed from ad libitum to a restricted access to feed, the rhythm of excretion is profoundly altered, whatever the length of the light period. Lebas and Laplace (1974) reported that in rabbits (8 weeks old) fed ad libitum, the hard faeces excretion was almost inexistent between 9h and 16h, reached a maximum at 20h and remained high until 8h. According to the same authors, the reduced hard faeces’ excretion between 9h and 16h could be linked with occurrence of the caecotrophy during this same period. In addition, Ruckebush and Fioramonti (1976) observed that in adult rabbits fed ad libitum, the soft faeces excretion occurs in only one phase of 7 hours, normally between 5h and 12h, while the hard faeces excretion takes place between 8h and 11h. On the other hand, Lebas and Laplace (1975) referred that a lower level of intake led to reduction of the amount of hard faeces excreted per 24h, resulted in a shorter excretion period (6.7 versus 9h) and in an earlier hour for faecal excretion.
2. Rabbit feeding behaviour after weaning

The rabbit feeding behaviour is very peculiar compared to other mammals, with special features, such as caecotrophy, associated with a particular digestive physiology, intermediate between the monogastric and the herbivore (Forthun-Lamothe and Gidenne, 2006).

2.1. Post-weaning feed intake

After weaning, the rabbit goes from a “mixed” milk and solid feed intake to a strict solid feed intake. From weaning, the daily feed intake increases correlative to the metabolic live weight and levels up at about 5 months of age. Taking as a reference an adult fed ad libitum (140-150 g dry matter/day, for example, for a 4 kg New Zealand White rabbit): at 4 weeks of age, a young rabbit eats 25% of the amount an adult eats, while its live weight is only 14% of the adult’s; at 8 weeks the relative proportions are 62% and 42%; at 16 weeks they are 100 to 110 and 87% (Gidenne and Lebas, 2005; Fortun-Lamothe and Gidenne, 2006). The animals’ growth reaches its highest level, between the weaning and 8 weeks of age (table 1), when consequently the feed conversion ratio is optimal. After that, the feed intake increases less quickly than the animals’ live weight which origin a reduction of the growth (Gidenne and Lebas, 2005).

Table 1: Daily feed intake, growth and feed conversion in the weaned domestic rabbit (Gidenne and Lebas, 2005)

<table>
<thead>
<tr>
<th>Periods of age</th>
<th>5-7 weeks</th>
<th>7-10 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily feed intake (g/day)</td>
<td>100-120</td>
<td>140-170</td>
</tr>
<tr>
<td>Growth (g/day)</td>
<td>45-50</td>
<td>35-45</td>
</tr>
<tr>
<td>Feed conversion (g of feed/g of growth)</td>
<td>2.2-2.4</td>
<td>3.4-3.8</td>
</tr>
</tbody>
</table>

The rabbit regulates its feed intake according to energy need, as for other mammals. Chemostatic mechanisms are involved, by means of nervous system and blood levels of compounds used in energy metabolism. In monogastric animals, the glycemia plays a key role in
food intake regulation (Gidenne and Lebas, 2005; Fortun-Lamothe and Gidenne, 2006). Since the rabbit is a monogastric herbivore, the main blood component regulating feed intake is not completely ascertain, but is likely to be the blood glucose level (Fortun-Lamothe and Gidenne, 2006). The digestible energy (DE) voluntary intake is proportional to metabolic live weight ($LW^{-0.75}$) and is about 900-1000 KJ/day/kg $LW^{-0.75}$. The chemostatic regulation appears only in a dietary DE concentration higher than 9-9.5 MJ/kg (Parigi-Bini and Xicatto, 1998; Gidenne et Lebas, 2005; Fortun-Lamothe and Gidenne, 2006). Below this level, a physical-type regulation is prevalent and linked to gut filling (Gidenne and Lebas, 2005; Fortun-Lamothe and Gidenne, 2006).

The rabbit fractionates its voluntary solid intake in numerous meals (30 to 40) (Prud'hon et al., 1975; Gidenne et Lebas, 2005; Fortun-Lamothe and Gidenne, 2006). The feed intake multiplication is probably related with the weak stomach’s storage ability. Once, the stomach’s storage ability is higher at the adult age, the number of feeding times per day at the adult age is lower than at 6 weeks (Prud'hon et al., 1975). At 6 weeks of age, the time spent to eat is over 3 hours per day, decreasing to less than 2 hours just after this period (Prud'hon et al., 1972; Lebas, 2002; Gidenne and Lebas, 2005). Nevertheless, daily feed intake increases from 98 to 160 g due to the augment of the amount of feed ingested in each feeding time (table 2) (Prud'hon et al., 1972; Gidenne and Lebas, 2005). The number of water drinking evolves in parallel to that of pelleted feed, and the time spent to drink is lower than that spent to eat (Fortun-Lamothe and Gidenne, 2006).

2.2. External factors affecting the rabbit feeding behaviour

2.2.1. Feed composition and appearance

After weaning, the feed intake regulation depends on the DE content of diet and fibre content. The feed intake level is better correlated with the fibres content than with the DE content of the feed (figure 4). The rabbit can adjust its DE intake when the ED level is located between 9-12 MJ/kg and when the rate of fibres is located among 10 and 25% of ADF (acid-detergent fibre). The fat incorporation in the feed (maintaining the fibre level present in the feed) increases the DE
content and provokes a light intake’s reduction. Other nutrients, such as the proteins and their equilibrium in essential amino acids, can modify the feed intake. For instance, an excess in methionine reduces at least 10% the feed intake of the growing rabbit (Gidenne and Lebas, 2005).

Table 2: Feeding behaviour evolution in 6 and 18 weeks old rabbits having free access to solid feed and water (Prud’hon et al., 1975; Gidenne and Lebas, 2005)

<table>
<thead>
<tr>
<th>Age (weeks)</th>
<th>6</th>
<th>12</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLID FEED (89 % of DM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total feed intake in 24 hours (g)</td>
<td>98</td>
<td>104</td>
<td>160</td>
</tr>
<tr>
<td>Number of meals in 24 hours</td>
<td>39</td>
<td>40</td>
<td>34</td>
</tr>
<tr>
<td>Feed intake per meal (g)</td>
<td>2.6</td>
<td>4.9</td>
<td>4.9</td>
</tr>
<tr>
<td>WATER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total water intake in 24 hours (g)</td>
<td>153</td>
<td>32.0</td>
<td>297</td>
</tr>
<tr>
<td>Number of water drinking in 24 hours</td>
<td>31</td>
<td>28.5</td>
<td>36</td>
</tr>
<tr>
<td>Average weight of a water drinking (g)</td>
<td>5.1</td>
<td>11.5</td>
<td>9.1</td>
</tr>
<tr>
<td>WATER/FEED RATIO (DM)</td>
<td>1.75</td>
<td>1.85</td>
<td>2.09</td>
</tr>
</tbody>
</table>

Figure 4: Relationship between the voluntary feed intake and feed composition, in the rabbit after weaning (Gidenne and Lebas, 2005)
The feed’s appearance plays as well an important role in the rabbit’s feeding behaviour. When the rabbit can choose, he prefers 97 % of the times a pelleted feed than non-pelleted one. Besides, a non-pelleted feed seems to disturb the intake’s circadian rhythm. The size of the pellets and their quality (hardness and durability) can also influence the rabbit’s feeding behaviour. Indeed, a reduction in the pellets’ diameter increases its hardness and provokes an intake reduction in the growing rabbit (Gidenne and Lebas, 2005).

2.2.2. Feed and water intake according to the environment

The rabbit’s energetic expenditures are dependent of the environmental temperature. Hence, the feed intake to face against these expenditures is also correlated with the environmental temperature. In fact, according with the table 3, it is possible to infer that between 5ºC and 30ºC, the rabbit’s feed intake decreases from 180 to 120 g per day and the water consumption increases from 330 to 390 g per day.

A deepest analysis of the rabbit feeding behaviour shows that, when the environmental temperature increases, the number of meals (solids and liquids) observed in 24 hours decreases (37 meals at 10ºC to 27 at 30ºC). However, if the amount of feed ingested in each meal is reduced (5.7 g/meal at 10ºC to 4.4 g at 30ºC), the amount of water ingested in each meal increases (11.4 g to 16.2 g per meal, from 10ºC to 30ºC) with the augmentation of the environmental temperature. In case of a total lack of water, when just dry feed (less than 14% of water) is available, the dry matter intake is annulled in 24 hours (Lebas, 2002; Gidenne and Lebas, 2005).

Table 3: Rabbit feeding behaviour according to the environmental temperature (Gidenne and Lebas, 2005)

<table>
<thead>
<tr>
<th>Environmental temperature</th>
<th>5ºC</th>
<th>18ºC</th>
<th>30ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity</td>
<td>80%</td>
<td>70%</td>
<td>60%</td>
</tr>
<tr>
<td>Pelleted feed intake (g/day)</td>
<td>182</td>
<td>158</td>
<td>123</td>
</tr>
<tr>
<td>Water consumption (g/day)</td>
<td>328</td>
<td>271</td>
<td>386</td>
</tr>
<tr>
<td>Water/feed ratio</td>
<td>1.80</td>
<td>1.71</td>
<td>3.14</td>
</tr>
<tr>
<td>Growth (g/day)</td>
<td>35.1</td>
<td>37.4</td>
<td>25.4</td>
</tr>
</tbody>
</table>
Other environmental factors are linked with the rabbit feed and water’s intake, such as the lightening schedule and the caging system. In a total absence of light (darkness 24h/24), the intake of the growing rabbit increases when compared with rabbits under a lightening schedule, and it is organised according to a circadian rhythm of 23.5 to 23.8 hours, with 5 to 6 hours dedicated to the caecotrophy. In continuous lighting, the feeding program is organised according to a circadian rhythm of 25 hours (Gidenne and Lebas, 2005).

The feed and water intake is reduced when the animals’ density in a cage increases, probably due to a greater competition between the animals to access to the feeding place and to a reduction of the animals’ mobility. This density effect is also observed in individually caged rabbits. At a same density, rabbits placed in a cage for 2 or 6 animals present the same intake. But, in a cage for 2, the rabbits spend less time eating (5.8% against 9.9% in a 10 hours lightening schedule). Finally, the number of feeding places (1 to 6) for a group of 10 rabbits fed ad libitum doesn’t influence their level of feed consumption. However, this is not necessarily verified when the animals are fed in a restricted way (Gidenne and Lebas, 2005).

3. Feed restriction in rabbit nutrition

In growing rabbit feeding, the animals usually have always access to the feed and ate ad libitum. In a restricted feeding system, either the access of the animals to the feed is not always allowed, or a fixed amount of feed is given.

There are two methods for restrict the intake of feed. In a “qualitative” restriction, the total amount of feed distributed to each animal is the same, but the feed composition can be changed: e.g. increasing the fibre level and reducing the digestible energy content (Feugier, 2002). A “quantitative” restriction can be applied according to two methods: the time for access to the feeder or the quantity of feed distributed can be reduced (Feugier, 2002; Szendrő et al., 2000). In addition, this can be applied for different time periods (e.g. feed restriction applied directly after weaning and ad libitum in the fattening period or vice-versa). For instance, in some periods of the production cycle, namely, during the growing period.
Applying a feed restriction may not always be easy and is time consuming when automatic feedings are not available. A possible alternative to this problem is, instead of make a feed restriction, make a hydric restriction (Boisot et al., 2004; Verdelhan et al., 2004; Foubert et al., 2007; Ben Rayana et al., 2008) because the feed consumption is directly correlated with the water consumption (Gidenne and Lebas, 2005). But, a hydric restriction has also several disadvantages, namely: the results obtained are less precise compared with feed restriction and hydric restriction is more harmful for the animal welfare than a feed restriction.

In the growing rabbit, an early feed restriction applied from post-weaning age, according to several authors, can be of interest to reduce post weaning digestive disorders, namely the Epizootic Rabbit Enteropathy syndrome (ERE), improves feed efficiency, reduces carcass fat deposition, induces compensatory growth and improves digestibility of nutrients during the restricted feeding period.

Limiting feed intake depresses growth during the period of restriction, but reduced growth can be later compensated by realimentation. This phenomenon of accelerated growth following a period of feed restriction is named “compensatory growth” (Tumova et al., 2002). Ledin (1984) reports the occurrence of compensatory growth in restricted fed rabbits (60% of the *ad libitum* feed intake; beginning of the realimentation period when the average weight of the rabbits in the litter reached 2.1 kg in a first experiment and 2.4 kg on a second one), measured as live weight gain, during realimentation. Perrier and Ouhayoun (1996) and Dalle Zotte et al. (2004, 2005), when comparing two different feed restriction patterns (70% of the *ad libitum* intake from 5 to 8 weeks of age and 90% of the *ad libitum* intake from 8 to 11 weeks of age, or vice versa) observed that at the end of fattening period (11 weeks), the rabbits that received the most liberal mode of rationing showed the best growth due to the compensatory growth rate which occurs when animals are initially restricted. Perrier (1998) report that 8 weeks old restricted-fed rabbits (30 and 50% of *ad libitum* intake) show an important compensatory growth during realimentation period, however they did not completely compensate their slow development. Tumova et al. (2002) report the occurrence of compensatory growth, following growth retardation for growing rabbits (6 and 7 weeks old). Besides, Gidenne et al. (2003) refer that the return to an *ad libitum* feed intake led to a
compensatory growth which is as higher as lower is the level of intake (*ad libitum*, 90, 80, 70, and 60 % of the *ad libitum* intake). Foubert *et al.* (2007) reported that, during the realimentation period, the animals initially submitted to a feed restriction (access to the feeder restricted to 6, 8 or 10 hours/day) showed a compensatory growth, even though, not totally compensating their growth retardation. Finally, lately, Foubert *et al.* (2008) report that feed restriction (30% of the *ad libitum* intake level) modified the growing curve of rabbits with a phenomenon of compensatory growth observed during the realimentation period, however not sufficient to compensate the body weight differences. Matics *et al.* (2008) found a minor compensatory growth in restricted rabbits allowed to consume for 9, 10, 12 or 14 hours between 4-5, 6-7, 7-8 or 8-9 weeks of age, respectively, then, for 24 hours onwards (9-11 weeks).


Gidenne *et al.* (2003) and Boisot *et al.* (2003) reported that a restricted feeding could be recommended for preventing post-weaning digestive disorders. Gidenne *et al.* (2003) demonstrated that during feed restriction, mortality and morbidity were significantly reduced from a feeding level of 80% and 70%, respectively. Besides, during an experimental reproduction of Epizootic Rabbit Enteropathy (ERE) syndrome, Boisot *et al.* (2003) showed the interest of a preventive restricted feeding system to reduce the negative impact of ERE on zootechnical performances in the growing rabbit. In this trial, a feeding level of 60% was more efficient than a feeding level of 80% in ERE syndrome conditions. The results from Boisot *et al.* (2003) and Gidenne *et al.* (2003) suggest that a feed restriction of at least -20% of the *ad libitum* level is necessary to reduce mortality and morbidity in growing rabbits. In addition, Foubert *et al.* (2008) state that a quantitative feed restriction (70%) is interesting in ERE conditions as it leads to less mortality and morbidity compared to the control group (*ad libitum*). However, several authors report as well that feed restriction had no effect on the animals’ health status. Perrier (1998) reported that,
at weaning age, rabbits could be subjected to a feed restriction period without compromising their viability (treatments: *ad libitum* between 35-77<sup>th</sup> days of age; restricted to 70% or 50% of the *ad libitum* level between 35-56<sup>th</sup> days of age and realimented between 56-77<sup>th</sup> days of age). Tumova et al. (2002) (treatments: *ad libitum* from 32 to 67 days of age; restriction period between 35-42<sup>nd</sup> or 42-49<sup>th</sup> of days of age (50 g/day or 65 g/day respectively) and realimentation after the restriction period) observed as well that feed restriction did not affect mortality. Later, Yakubu et al. (2007) also refers that feed restriction did not influence mortality of rabbits. The rabbits were subjected to three dietary treatments during all growing period, *ad libitum* (24 hours) feeding, 8 hours feeding (7h-15h) and skip-a-day feeding) and the only mortality recorded in rabbits subjected to skip-a-day feeding was not linked to dietary effect as revealed by post mortem examination. Foubert et al. (2008) also reported that animals in good sanitary conditions (treatments: *ad libitum* during the entire growing period; feed restriction to 70% of the *ad libitum* level and then realimentation) and Matics et al. (2008) did not find significant influence of a feed restriction (70% of the *ad libitum* intake in the entire growing period) in the mortality. Moreover, Begaoui et al. (2008) referred that the sanitary state of the animals did not differ between levels of intake (*ad libitum*, 85 or 70% of the *ad libitum level* in the whole fattening period).

Nevertheless, until now; few are known about what is the ideal feed restriction to improve the digestive process and health of a growing rabbit. According to Gidenne et al. (2003), there is a need for objective information about the effects of a quantitative feed restriction on the digestive physiology and the digestive health.

Ledin (1984) and Di Meo et al. (2007) report higher digestibility coefficients in restricted-fed rabbits. Tumova et al. (2004) report that nutrient digestibility was improved in restricted-fed rabbits (6, 7 and 8 weeks old), but only during the restriction period, and not during the realimentation period. Feugier (2002) did not find significant effects of a restricted feeding on the digestibility for growing rabbits (6 weeks old), but after an adaptation period to restriction of 6 days. Xicatto and Cinetto et al. (1988) reported that a feed restriction caused a significant increase in the digestibility of dry matter, organic matter and crude protein in 14 weeks old rabbits. In addition, Xicatto et al. (1992) report that the level of feed intake did not modify the digestibility of the ether extract, ash,
crude fibre and fibre fractions, but it provokes a significant increase in the digestibility of dry matter, organic matter, energy, crude protein and cell content in rabbits with 8 weeks of age. Besides, Diaz Arca et al. (1999), referred that the digestibility of organic matter, crude protein, ether extract and ash did not differ between levels of intake (ad libitum, 60, 40 or 10% of the ad libitum intake) and only the digestibility of neutral detergent fibre (NDF) was significant lower for animals receiving only 10% of the ad libitum intake (digestibility measures made in rabbits 7 weeks old). According to Diaz Arca et al. (1999), changes in digestibility with restricted feeding can be caused by changes in the digesta's rate of passage. Indeed, Ledin (1984b) concluded that the feeding level has a definite influence on the rate of passage, being the digesta's rate of passage lower at restricted feeding. This lower rate of passage would take to longer retention time of the feed in the gastro-intestinal tract, which according to Ledin (1984b), Gidenne et al. (1993), Diaz Arca et al. (1999) results in a better digestibility.

Therefore, due to all these uncertainties, it is difficult to determine the consequences of a reduced level of intake on the digestion. Finally, no studies dealt with the effect of a reduced time for access to the feeder on digestion in the rabbit.

Hence, in this trial, the feed digestibility was measured in growing rabbits, to evaluate the exact relationship between the levels of intake, the time for access to the feeder and the digestive answer of the growing rabbit.
III. Experimental work

1. Material and methods

1.1. General description

The experiment was set up in a bi-factorial (2x2) design. The two factors were the level of intake (ad libitum = 100% vs. restricted = 75%, code 100 and 75, respectively) and the time for access to the feeder (free access to the feeder all the day (24h per day) or limited access to the feeder (allowed 18 hours per day from 16h30 until 10h30), code 1D and 2D, respectively).

The animals were divided in four groups according with the feeding scheme presented: the animals having access to the feeder 24 hours per day (1D100 (100 % ad libitum) and 1D75 (75% ad libitum)), and those having access to the feeder 18 hours per day (2D100 and 2D75) (figure 5).

![Figure 5: Experimental treatments in first period of essay](image)

Table 4: Experimental design

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Age (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>32 – 63</td>
</tr>
<tr>
<td>1D100</td>
<td>Ad libitum; Free access to the feeder</td>
</tr>
<tr>
<td>1D75</td>
<td>Restricted 75%; Free access to the feeder</td>
</tr>
<tr>
<td>2D100</td>
<td>Ad libitum; Limited access to the feeder (access 18 h/day)</td>
</tr>
<tr>
<td>2D75</td>
<td>Restricted 75%; Limited access to the feeder (access 18 h/day)</td>
</tr>
</tbody>
</table>
The animals were restricted and/or had a daily limited access to the feeder from weaning (32 days) until the 63 days of age, then, all the four groups were fed ad libitum till 70 days (slaughter age and end of experiment). The ad libitum feeding system and/or a free access to the feeder after the 63 days of age was applied to verify the occurrence or not of compensatory growth (table 4).

1.2. Animals and housing

This experiment involved 48 rabbits weaned at 32 days of age (weaned at 30 of March 2007) divided in four groups of 12, according to litter origin and weaning weight. The animals were housed in metabolic individual cages.

The animals had free access to water, and the lighting schedule was 10 hours of light (7h00 until 17h00). The environmental temperature inside of the building was around 20 °C.

1.3. Feeding strategy

The animals were fed with an experimental diet (see table 5), which composition covered the nutritional needs of the growing rabbit.

In the first day of the trial (D1=32 days of age), the theoretical quantities of feed to be distributed to the groups 1D75 and 2D75, in order to reach a 25% reduction of the intake were estimated according to the age of the animals (table 6). Then, from day 4 (D4=39 days of age) onwards the daily feed intake of the groups 1D100 and 2D100 was measured in each date mentioned in the table 6, to adjust the restriction level to the real voluntary feed intake (g/day/rabbit). Thus, from day 4 onwards, the intake of the group 1D75 and group 2D75 was determined taking in account the real voluntary feed intake of the group 1D100 and 2D100, respectively.

The distribution of the meal in the groups 1D100 and 1D75 was made between 7h30 and 8h30 in the morning. In the other two groups, 2D100 and 2D75, the feed was distributed each
morning at 8h00. However, the access of the animals of these two last groups to the feeder was not allowed between 10h30 (3h30 after the beginning of the lightening period) and 16h30 (30 minutes before the end of the lightening period). This schedule was chosen in order to create a maximum digestive emptiness between the two feeding times.

Table 5: Experimental diet – Ingredients and determined chemical composition

<table>
<thead>
<tr>
<th>Ingredients (%)</th>
<th>Chemical composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat bran</td>
<td>Dry matter 87.3*</td>
</tr>
<tr>
<td>&quot;Milurex®&quot;</td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>Crude protein 16.3*</td>
</tr>
<tr>
<td>Wheat</td>
<td>NDF 33.6*</td>
</tr>
<tr>
<td>Soya bean meal</td>
<td>ADF 20.2*</td>
</tr>
<tr>
<td>Sunflower meal</td>
<td>ADL 6.6*</td>
</tr>
<tr>
<td>Alfalfa meal</td>
<td>Cellulose Van Soest 13.6*</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>Hemicelluloses Van Soest 13.4*</td>
</tr>
<tr>
<td>Beet pulp</td>
<td>Starch (enzymatic) 15.0</td>
</tr>
<tr>
<td>Grape seed meal</td>
<td>Crude Fibre 16.1</td>
</tr>
<tr>
<td>Beet molasses</td>
<td>Crude Fat 2.1</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>Digestible energy, kcal/kg 2300</td>
</tr>
<tr>
<td>L-lysine &quot;25 (wheat50/CA25)&quot; Premix</td>
<td></td>
</tr>
<tr>
<td>LHT004NE® 1% (salt included 0.5%)</td>
<td></td>
</tr>
<tr>
<td>Total 100</td>
<td></td>
</tr>
</tbody>
</table>

* Chemical composition determined by laboratorial analysis

Summarising the above procedures:

- Weaning (D1=32 days of age) until 31 days after the weaning (J63): the animals were fed *ad libitum* or 75% *ad libitum* (100 vs. 75) and had access to the feeder all the day.
(24 h/24) or access to the feeder during 18 hours per day (from 16h30 to 10h30) (1D vs. 2D);

- From 31 days after the weaning (morning) until 70 days (slaughtering age): all the animals were fed *ad libitum* and had access to the feeder during 24h/24.

<table>
<thead>
<tr>
<th>Table 6: Feed restriction programme according to the age</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (days)</strong></td>
</tr>
<tr>
<td>Days after weaning</td>
</tr>
<tr>
<td>Average live weight (g)</td>
</tr>
<tr>
<td>Theoretical voluntary intake (g/day/rabbit) μ</td>
</tr>
<tr>
<td>Feed to distribute to 1D75 and 2D75 (g/day/rabbit) £</td>
</tr>
</tbody>
</table>

μ: This value was measured at INRA-SRC in 2002 for a similar feed;
£: The amount of feed to distribute, each day, is expressed in g/day/animal. So, the total amount to be distributed should be calculated, according to the total number of animals present in the cage.

1.4. Measurements

1.4.1. Measurement of apparent digestibility

The general objective was to measure the apparent digestibility of the feed and at the same time, to measure the growth performance and the level of intake of the animals in the entire animal growth period (32-70 days old).

The apparent digestibility of a nutrient represents the amount of the same nutrient that crosses the intestinal barrier. The amount of digested nutrient is estimated by difference between the nutrient intake and the nutrient excreted in hard faeces (thus, not digested), during a
determined period of time. Then, the apparent digestibility coefficient (ADC) of a nutrient is
calculated using the following formula: \( \text{ADC (\%)} = \left( \frac{\text{Intake-Excreted}}{\text{Intake}} \right) \times 100 \).

The digestibility was measured between 49 and 53 days of age (thus after an adaptation
period of 17 days), according to the European procedure. This included a total collection of the
faeces and a precise measure of the intake of each animal during 4 consecutive days. The faeces
were stored at -20°C in a plastic bag (for each animal). The feed and faeces samples were then
dried according to the European procedure (E.G.R.A.N., 2001).

1.4.2. Measurement of the faecal excretion rhythm

The rhythm of faecal excretion was measured during a period of 48 hours. The animals
were housed in metabolic individual cages. The faeces collection was made with a frequency of 2
hours by an automatic faeces collector.

The measures were made in two series, each one constituted by 10 animals (2 animals of
the group 1D100, 2 animals of the group 2D100, 3 animals of the group 1D75 and 3 animals of the
group 2D75). After an adaptation period of 3 days, the measures took place between the 56 and
57 days (of age) for the first series and between the 60 and 61 days (of age) to the second series.

The collected faeces were dried during 24 hours at a temperature of 103°C and then
weighed.

The intake and live weight of the animals was measured in the beginning of the adaptation
period and in the end of the measurement period.

1.4.3. Growth and feed intake control

All the animals were identified at weaning. The live weight and the intake of each animal of
the groups 1D75 and 2D75 were controlled weekly until the end of the experiment (70 days of age)
(see dates in table 6). The intake control of the groups fed \textit{ad libitum} (1D100 and 2D100) was
made at the end of each period (D1-D3, D4-D7, etc), in order to adjust at 75%, the feed restriction
level of the groups 1D75 and 2D75, respectively.
After the restriction period, the level of intake was only controlled in the day 63 (beginning of the *ad libitum* period for all the animals) and then in the day 70 (end of the experiment).

When an animal died, the feed not consumed in that day was weighted. Besides, when the feed distributed to the restricted animals was not all consumed, the excess was also weighted.

In the specific case of the groups 2D100 and 2D75, in order to analyse the real repartition of the intake between the two feeding times, the intake level of the first period of access to the feeder (8h00-10h30) as well as of the second period (16h30-8h00) were controlled. These supplementary controls were made as indicated below:

- Day 1 of the experiment (weaning age (32 days)) - Friday;
- Day 6 (37 days of age) - feed not consumed was weighted Wednesday at 10h30 and Thursday at 8h00;
- Day 11 (42 days of age) - feed not consumed was weighted Monday at 10h30 and Tuesday at 8h00;
- Day 18 - feed not consumed was weighted Monday at 10h30 and Tuesday at 8h00;
- Day 25 - feed not consumed was weighted Monday at 10h30 and Tuesday at 8h00.

The wastage of feed, mainly during the first week of the experiment was controlled, in order to estimate the quantity of wasted feed located in the cage. Two “qualitative” categories of wasted feed were formed: absence (no wasted feeds in the cage, code GO), moderated presence (10 until 20 granules, code G1), significant presence (more than 20 granules, code G2).

The feed consumption is directly correlated with the water consumption, so the watering system was verified regularly.

### 1.4.4. Control of the health status

The mortality of the young rabbits was controlled each day. When an animal died, the feed not consumed in that day was controlled. In addition, the cause of the death was determined and registered. Autopsies were performed. The morbidity of the young rabbits was controlled each Monday when the animals were weighted.
1.5. Analytical methods

One sample of 1kg of feed was constituted in the day 49. Half of this sample was stored for a long term (at 5°C under vacuum). The other half was used to determine the level of dry matter (DM), crude ash (CA), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), ADL (acid detergent lignin) and gross energy (GE).

The total amount of faeces contained in the plastic bag was dried during 24h at a temperature of 80°C. After that, half of that material was completely dried at a temperature of 103°C during 24h. Before grinding the faeces to proceed to chemical analyses, the apparent digestibility of the dry matter was calculated. After that, a maximum of 8 faeces per group was used to determine their content in DM, CA, CP, NDF, ADF, ADL and GE.

1.5.1. Dry matter (DM) and crude ash (CA)

In order to determine the DM, the collected samples were dried during 24 h at 103 °C in an oven. The residue obtained was then incinerated in an oven at 550 °C during 5h. The weight of the ashes corresponds to the CA content. The organic matter (OM) content represents the material that was eliminated during the incineration and was determined by calculating the difference between the DM and CA content of the samples: OM = DM – CA.

1.5.2. Crude protein (CP)

The determination of the CP content was made according to the Dumas procedure using a nitrogen auto-analyser machine (LECO mod. FP428). First, the sample was burned at 850 °C in the presence of the oxygen. After an oxidation and reduction of the mixture of gazes formed, the NH+ fractions formed were quantified. The CP content was calculated by multiplying the nitrogen content of the sample by 6.25 (coefficient that represents the average nitrogen content present in the proteins in feeds or faeces): CP = 6.25 x Nitrogen content.
1.5.3. Fibrous fractions

The different fibrous fractions content was determined according to the Van Soest sequential method (1991), normalised by the A.F.N.O.R. (1997) using a semi-automatic apparatus (Fibertec Tecator Ldt).

The neutral detergent fibre (NDF) fraction was obtained after the action of a detergent (lauryl sodium sulphate, 104 mM; Merck: 822050) in a neutral and buffered solution and of a chelating agent (EDTA, 55 mM; Prolabo: 20302.293) that solubilises the cellular content (proteins and sugars) and pectic substances (1h at 100 ºC). This NDF fraction is mainly constituted by hemicelluloses, cellulose and lignin. The acid detergent fibre (ADF) is obtained by hydrolysing the hemicelluloses fraction of the NDF residue, after the action of an acid detergent during 1h at 100ºC. The result of the sulphuric acid (72%) action on the ADF residue during 3h is the acid detergent lignin (ADL). The content in hemicelluloses and cellulose can be determined by:

\[
\text{Hemicelluloses} = \text{NDF} - \text{ADF} \\
\text{Cellulose} = \text{ADF} - \text{ADL}
\]

In the feeds rich in starch, the first hydrolyse is performed in the presence of a thermo stable amylase (Thermamyl®, AFNOR 1997). However, in this study, there was no need to perform the first hydrolyse in the presence of a thermo stable amylase.

1.5.4. Gross energy (GE)

The determination of the GE content of the samples is done with a calorimetric bomb. Unfortunately, due to technical problems with the calorimetric bomb available in the laboratory, the crude energy content of the feed (and faeces) was not determined.
1.6. Statistical analysis

The data was statistically analysed using the software “SAS”. A GLM procedure was made to compare the data obtained (live body weight, daily feed intake, growth, feed conversion and digestibility). The effect of level of feed intake, the time for access to the feeder and its interaction was considered.
2. Results and discussion

2.1. Feed analysis

In the table 7 are presented the results relating to the chemical composition of the diet determined by laboratorial analysis. In addition, the theoretical composition of the diet is also presented which allows a comparison between both.

<table>
<thead>
<tr>
<th>Chemical component</th>
<th>Theoretical values* (% gross)</th>
<th>Determined values (% gross)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>-</td>
<td>87.3</td>
</tr>
<tr>
<td>CP</td>
<td>16.0</td>
<td>16.3</td>
</tr>
<tr>
<td>NDF</td>
<td>32.5</td>
<td>3.6</td>
</tr>
<tr>
<td>ADF</td>
<td>18.6</td>
<td>20.2</td>
</tr>
<tr>
<td>ADL</td>
<td>5.2</td>
<td>6.6</td>
</tr>
<tr>
<td>Cellulose Van Soest</td>
<td>13.4</td>
<td>13.6</td>
</tr>
<tr>
<td>Hemicelluloses Van Soest</td>
<td>13.9</td>
<td>13.4</td>
</tr>
<tr>
<td>Starch (enzymatic)</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td>Crude Fibre</td>
<td>16.1</td>
<td></td>
</tr>
<tr>
<td>Fat content</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Digestible energy, kcal/kg</td>
<td>2300</td>
<td></td>
</tr>
</tbody>
</table>

* Theoretical chemical composition according to feed formulation

The feed analysis in the laboratory confirmed the theoretical values concerning the chemical composition of the diet.

2.2. Effect of the level of feed restriction and time for access to the feeder in the live weight

In the table 8, figure 6 and 7, the animals' live weight progression according to the age is illustrated. At the beginning of the experiment, the allotment was correctly performed since the live weights at 32 days were identical between the different treatments.

It is also possible to conclude that there was no significant interaction between the level of feed intake and the time to for access to the feeder.
Table 8: Evolution of the rabbits’ live weight (g) according to the age

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>Level of feed intake (%)</th>
<th>Time for access to the feeder</th>
<th>CV%</th>
<th>Pr&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 75 1D 2D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>843 839 840 841</td>
<td>10.6</td>
<td>0.89</td>
<td>0.99</td>
</tr>
<tr>
<td>42</td>
<td>1371 1194 1264 1303</td>
<td>8.5</td>
<td>&lt;0.001</td>
<td>0.22</td>
</tr>
<tr>
<td>63</td>
<td>2388 1956 2203 2178</td>
<td>8.2</td>
<td>&lt;0.001</td>
<td>0.57</td>
</tr>
<tr>
<td>70</td>
<td>2727 2510 2650 2616</td>
<td>5.6</td>
<td>&lt;0.01</td>
<td>0.71</td>
</tr>
</tbody>
</table>

100: *Ad libitum*;
75: Restricted to 75% of the *ad libitum* intake;
1D: Free access to the feeder during all the day (24h/24);
2D: Access to the feeder 18 hours per day (between 16h30 and 10h30);
Non significant (NS) : P> 0.05; Significant (S) : P < 0.05.

As expected, from the 32 until the 63 days of age (end of the restriction period), the animals restricted to 75% of the *ad libitum* intake present a lower live weight (-18%, P<0.001) than those fed *ad libitum*. This confirms the results obtained by Perrier (1998), where a reduced level of intake (50% and 70% of the *ad libitum* intake) provoked a reduction of the live weight (-32.9 and –20.5%, respectively) at the end of the restriction period (35-56 days). Foubert *et al.* (2008) reported that a restricted feeding (70% of the *ad libitum* level) took to a lower live weight (-8.8%) at the end of restriction period (32-53 days), although this value is less significant than the one referred by Perrier (1988) for the same level of intake. It also confirms the results of Boisot *et al.*, (2003) who reported that a feed restriction (60% and 80% of the *ad libitum* level) took to a lower live weight (respectively, -17.5 and -7%), at the end of the restriction period (34-54 days). In addition, Gidenne *et al.* (2003) observed that rabbits having reduced feed intake level (60, 70, 80 or 90% of the *ad libitum* intake), at the end of the restriction period (weaning till approximately 54 days) showed as well lower live weights (-20.5, -14.4, -9.7 and 5.9%, respectively). In reverse, the time for access to the feeder did not significantly affect the live weight whatever the age, during the restriction period. This is not in consonance with the findings of Foubert *et al.* (2007) and Matics *et al.* (2008) that observed that during the restriction period (32-53 days and 28-63 days), the body weight of rabbits having a reduced feeding time was lower. However, in these studies, animals had a reduced feeding time (6, 8, 9, 10, 12 and 14 hours/day) than in the present study (18 hours/day).
Nevertheless, at 42 days of age, animals having lower time for access to the feeder (-6 hours) present a higher live weight than animals having free access to the feeder 24h/24, while at 63 days this tendency is reversed. This live weight’s difference can be connected to a period of adaptation of the animals’ feeding behaviour.

**Figure 6: Live weight according to age and level of intake** (100: “*Ad libitum*” and 75: “Restricted to 75% of the *ad libitum* intake”)

At 70 days of age (end of the trial), the restricted animals did not recover entirely their live weight (-8%, \(P<0.01\)) compared to *ad libitum* groups (figure 6). It is in accordance with the results obtained by Perrier (1998) that showed that compared with the *ad libitum* group, the restricted groups (50 and 70% of *ad libitum* level) presented significantly lower final body weights (-5.9 and -
9.4%, respectively). Besides, Boisot et al., (2003) reported that rabbits having a lower level of intake (60 and 80% of the ad libitum intake) presented lower final body weights (-7.2 and -2.7%, respectively). For a feed intake of 70% of the ad libitum level, Foubert et al. (2008) refers that the final body weight was significantly lower in the restricted group (-4.5%). According to Gidenne et al. (2003), there is a moderate impact of the level of feed intake in the final body weight: a decrease of 1% in the level of feed intake takes to a decrease of -4.5g in the final body weight. However, the animals with a reduced time of access time to the feeder (-6 hours) presented a similar live weight to those having free access (24h/24) to the feeder (figure 7). Yakubu et al. (2007) have already reported that, the final body weights of rabbits having free access or -16 hours of access to the feed were not significantly different. Reversely, Foubert et al. (2007) and Matics et al. (2008) referred that the final body weights of the rabbits having a reduced feeding time (6, 8, 9, 10,12 and 14 hours/day) was lower than those having free access 24h/24.

2.3. Effect of the level of feed restriction and time for access to the feeder on the growth

Analysing the daily weight gain evolution during the experimental period (table 9) is possible to conclude that the interaction between the level of feed restriction and time for access to the feeder on weight gain was not significant.

Between 32 and 63 days of age, the weight gain was proportionally reduced (-26.8%, P<0.001) according to the level of feed restriction. The lower growth of the restricted animals compared with those fed ad libitum during the restriction period has already been reported by Ledin (1984) and confirmed by Perrier (1988), Tumova et al. (2002), Boisot et al., (2003), Gidenne et al. (2003) and Foubert et al. (2008).

Ledin (1984) referred that restricted-realimented rabbits, during the restriction period presented a lower growth (-33.5% and -37.7% for restricted feeding started at 1.0 kg or 1.6kg of live weight, respectively) compared with those fed ad libitum. Tumova et al. (2002) reported that during the restriction period, weight gain in restricted rabbits was about 60-70% lower than in full-fed rabbits. In addition, Foubert et al. (2008) reported that daily weight gain was significantly lower
(-14.7%) for the restricted group (70% of the ad libitum level), during the restriction period. Perrier (1998) and Boisot et al., (2003), when comparing different levels of feed restriction observed that rabbits having the higher level of feed restriction presented as well the lower growth. Finally, according to Gidenne et al. (2003) an increase of 1% in the level of feed restriction takes to a decrease of -0.5 g/day in the growth.

Concerning the time for access to the feeder, during the same period, it is possible to conclude that it did not significantly influence the weight gain, except between 42 and 63d of age when it was 11% (P<0.01) lower for rabbits having a reduced feeding time (-6 hours). The negative effect of a reduced time access to the feeder in the daily weight gain is directly correlated with the phenomenon already referred in the text: lower live weight at 42 days for rabbits having access to the feeder 24h/24 compared with those having access only during 18 hours (between 16h30 and 10h30) and the opposite tendency at 63 days. Nevertheless, in accordance with the findings of Foubert et al. (2007), during the restriction period rabbits with a reduced time to access to the feeder presented as well lower growth. However, in this later study, the rabbits have had a reduced feeding time (6, 8 or 10 hours/day) than in the present experiment (18 hours/day), what can explain the differences found.

Table 9: Evolution of the daily weight gain (g/day) according to periods of age

<table>
<thead>
<tr>
<th>Periods of age (days)</th>
<th>Level of feed intake (%)</th>
<th>Time for access to the feeder</th>
<th>CV%</th>
<th>Pr&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intake</td>
<td>75</td>
<td>1D</td>
<td>2D</td>
</tr>
<tr>
<td>32-42</td>
<td>52.9</td>
<td>35.6</td>
<td>42.3</td>
<td>46.2</td>
</tr>
<tr>
<td>42-63</td>
<td>48.5</td>
<td>37.7</td>
<td>46.5</td>
<td>41.3</td>
</tr>
<tr>
<td>32-63</td>
<td>49.8</td>
<td>36.5</td>
<td>45.0</td>
<td>43.0</td>
</tr>
<tr>
<td>63-70</td>
<td>45.3</td>
<td>75.2</td>
<td>55.3</td>
<td>61.0</td>
</tr>
<tr>
<td>32-70</td>
<td>49.6</td>
<td>43.7</td>
<td>47.4</td>
<td>46.7</td>
</tr>
</tbody>
</table>

100: Ad libitum;  
75: Restricted to 75% of the ad libitum intake;  
1D: Free access to the feeder during all the day (24h/24);  
2D: Access to the feeder 18 hours per day (between 16h30 and 10h30);  
Non significant (NS) : P> 0.05; Significant (S) : P < 0.05.
During the *ad libitum* period (63-70 days), the restricted animals showed a 66% (P<0.001) higher weight gain compared with those fed *ad libitum*. Ledin (1984) reported that, during realimentation (started at 2.1kg or 2.4kg of live weight, respectively), rabbits showed some compensatory growth measured as live weight gain (+20.8%). However, the restriction was applied in older animals, what may explain the difference between both values. Tumova *et al.* (2002) referred that in the week after feed restriction, weight gain was higher by 40% than in rabbits fed *ad libitum*. Besides, for a feed restriction of 70% of the *ad libitum* intake, Foubert *et al.* (2008) referred that restricted groups had a better daily weight gain (+7.9%), thanks to compensatory growth. Perrier (1988) reported the occurrence of compensatory growth during realimentation, outlining that rabbits under a higher feed restriction presented a lower growth compensation (+47.4% and +55.1% for a level of intake of 50% and 70% of the *ad libitum*, respectively). Boisot *et al.* (2003), and Gidenne *et al.* (2003) observed the inverse tendency and Gidenne *et al.* (2003) referred that during realimentation, the occurrence of compensatory growth follows a linear relationship with the level of restriction (+7.8, +10.8, +18.4 and +26.7% for 90, 80, 70 and 60% of *ad libitum* intake).

In relation to the time for access to the feeder, as it was verified between the 32 and 63 days of age, during the 63 and 70 days, it doesn't have a significant influence on the daily live weight gain. Matics *et al.* (2008) have already reported that, during the realimentation period there were no significant differences between the body weight gain of animals having or not a reduced access to the feeder. However, in this study, during the restriction period, the feeding time gradually increased (9, 10, 12 or 14 hours between 4-5, 6-7, 7-8 or 8-9 weeks of age) what can function as a kind of realimentation and mask the occurrence of compensatory growth when returning to a feeding time of 24h/24. Nevertheless, these findings contradict the observations made by Foubert *et al.* (2007) that reported that during realimentation, animals having a later reduced access to the feeder (access restricted to 6, 8 or 10 hours/day) showed a strong compensatory growth (35.1, 28.7 and 24.3%, respectively), compared with animals having access to the feeder 24h/24.
Between 32 and 70 days of age, a significant negative (-11.8%, P<0.001) effect of the level of feed restriction was found for the weight gain. This is actually correlated with the non live weight’s recovery at 70 days of age observed in the restricted animals, and already demonstrated by Ledin (1984), Perrier (1998), Boisot et al., (2003), Gidenne et al. (2003) and Foubert et al. (2008). These authors referred that during the whole fattening period (restriction plus realimentation), daily weight gain was lower (between -6.2 and -14.8%) for restricted groups as the animals didn't compensate totally the growth retardation occurred during the restriction period. In addition, Gidenne et al. (2003) reported that there is a negative linear correlation between the feed restriction and growth. Reversely, during the same period, no significant differences were found between rabbits having free (24h/24) or reduced (-6 hours) access to the feeder. Nonetheless, Foubert et al. (2007) reported that a reduced access to the feeder (6, 8 or 10 hours/day) induced lower growth (-10.9, -6.7 and –5.7%, respectively), during the whole fattening period. Besides, Matics et al. (2008) reported a 3% lower growth during the entire fattening period, in rabbits having less time to access to the feeder (9, 10, 12 or 14 hours between 4-5, 6-7, 7-8 or 8-9 weeks of age).

2.4. Effect of the level of feed restriction and time for access to the feeder on the daily feed intake

As it was referred during the description of the feeding strategy, during the restriction period, the amount of feed to distribute to the restricted animals was calculated taking in account the intake of the groups fed ad libitum.

Observing the table 10 that shows the evolution of the daily feed intake according to the different periods of age, it is possible to conclude that during the restriction period, the real level of intake of the restricted animals (72%) is close to the theoretical value (75 %).

During all the experimental period, there isn’t any effect of the interaction between the level of feed restriction and time for access to the feeder in the daily feed intake of the animals. At the beginning of the restriction period (between the day 32 and 35), some animals did not eat the whole quantity of feed distributed daily. This was probably due to a delay for adaptation to the conditions of the experiment (weaning, new cage, new diet).
Table 10: Evolution of the daily feed intake (g/day) according to periods of age

<table>
<thead>
<tr>
<th>Periods of age (days)</th>
<th>Level of feed intake (%)</th>
<th>Time for access to the feeder</th>
<th>CV%</th>
<th>Pr&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>75</td>
<td>1D</td>
<td>2D</td>
</tr>
<tr>
<td>32-42</td>
<td>106.9</td>
<td>72.8</td>
<td>90.6</td>
<td>89.0</td>
</tr>
<tr>
<td>42-63</td>
<td>155.8</td>
<td>114.2</td>
<td>139.1</td>
<td>136.0</td>
</tr>
<tr>
<td>32-63</td>
<td>140.3</td>
<td>100.9</td>
<td>124.4</td>
<td>121.7</td>
</tr>
<tr>
<td>63-70</td>
<td>196.9</td>
<td>213.6</td>
<td>203.3</td>
<td>204.9</td>
</tr>
<tr>
<td>32-70</td>
<td>152.4</td>
<td>122.2</td>
<td>140.7</td>
<td>137.8</td>
</tr>
</tbody>
</table>

100: *Ad libitum*; 75: Restricted to 75% of the *ad libitum* intake; 1D: Free access to the feeder during all the day (24h/24); 2D: Access to the feeder 18 hours per day (between 16h30 and 10h30); Non significant (NS) : P> 0.05; Significant (S) : P < 0.05.

During all the experimental period, there isn’t any effect of the interaction between the level of feed restriction and time for access to the feeder in the daily feed intake of the animals. At the beginning of the restriction period (between the day 32 and 35), some animals did not eat the whole quantity of feed distributed daily. This was probably due to a delay for adaptation to the conditions of the experiment (weaning, new cage, new diet).

In the *ad libitum* period (realimentation), as expected, the restricted animals have a higher daily intake (+8.5%, P<0.01) compared to non restricted animals. Ledin (1984) had already reported that restricted-fed rabbits during realimentation showed a tendency to consume more feed per day than those that were fed continuously *ad libitum*. However, Gidenne *et al.* (2003) and Foubert *et al.* (2008) reported that there were no significant differences in the daily feed consumption during realimentation between restricted-realimented and continuously *ad libitum* fed rabbits. Boisot *et al.*, 2003 observed that restricted rabbits (80% of *ad libitum* intake) had even lower daily feed intake (-18.4%, P<0.001) than *ad libitum* ones, during realimentation. However, during all the experimental period, restricted-realimented rabbits had an average daily feed intake lower (-19.8%, P<0.01) than those fed continuously *ad libitum* as reported by Ledin (1984) and confirmed by Gidenne *et al.* (2003), Boisot *et al.*, (2003) and Foubert *et al.* (2008) (between -2.3 and -29.3%).
The time for access to the feeder did not affect significantly the feed intake during the restriction period. This is not in accordance with the findings of Foubert et al. (2007) that reported that during the restriction period, animals having a reduced feeding time (6, 8 or 10 hours/day) had as well a lower daily feed intake (-33, -23.5 or -19.8%, respectively). Besides, Matics et al. (2008) reported significant differences in the daily intake (-26.7 and -18.3%, respectively) in rabbits having reduced access to the feeder (9 hours/day between 28-35 days and 10 hours/day between 42-49 days), while between 49-63 days (access to the feeder 12 and 14 hours/day, between 49-56 days, and 56-63 days, respectively), no significant differences were found. Castello and Gurri (1992), after barring the access of fattening rabbits to the feeder during 6 hours per day as well, have already referred that a reduced access to the feeder depressed feed intake, but not significantly.

During the realimentation period (day 63 to 70), the average daily feed intake was not significantly affected by the time for access to the feeder. However, rabbits having a reduced access to feed (-6 hours per day had a slight higher mean value (204.9 g) compared to the rabbits having free access to the feed (203.3 g). Foubert et al. (2007) reported a strongest effect of the time to access to the feeder in the daily feed intake during the realimentation period, when the return to a feeding time of 24h/24 resulted in an increased feed consumption by the animals having previously a reduced time of access to the feeder (+9.7, +8.8 and +8.2% for animals having 6, 8 or 10h/day access to the feeding place) compared with animals fed continuously ad libitum. During all the fattening period (32-70 days), the average daily feed intake was not significantly affected by the time for access to the feeder, as it would be expected once there is no significant effect of the time for access to the feeder in the daily feed intake, during the restriction or realimentation period. This is not in accordance with the findings of Foubert et al. (2007). According to these authors, during all the fattening period; animals having a reduced access to the feeder (6, 8 or 10h/day) had as well a lower daily feed intake (-17, -11.3 and -7.9%, respectively). In addition, Matics et al. (2008) reported a significantly lower feed intake for rabbits having a reduced feed intake (-5%, P<0.001).
2.5. Effect of the level of feed restriction and time for access to the feeder on the feed conversion

Whatever the period, there was any significant interaction between the level of feed restriction and time for access to the feeder on the feed conversion (table 11).

Table 11: Evolution of the feed conversion according to periods of age

<table>
<thead>
<tr>
<th>Periods of age (days)</th>
<th>Level of feed intake (%)</th>
<th>Time to access to the feeder</th>
<th>CV%</th>
<th>Pr&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>75</td>
<td>1D</td>
<td>2D</td>
</tr>
<tr>
<td>32-42</td>
<td>2.03</td>
<td>2.08</td>
<td>2.15</td>
<td>1.96</td>
</tr>
<tr>
<td>42-63</td>
<td>3.23</td>
<td>3.06</td>
<td>3.00</td>
<td>3.30</td>
</tr>
<tr>
<td>32-63</td>
<td>2.82</td>
<td>2.78</td>
<td>2.77</td>
<td>2.83</td>
</tr>
<tr>
<td>63-70</td>
<td>4.51</td>
<td>2.87</td>
<td>3.94</td>
<td>3.67</td>
</tr>
<tr>
<td>32-70</td>
<td>3.07</td>
<td>2.80</td>
<td>2.96</td>
<td>2.95</td>
</tr>
</tbody>
</table>

100: Ad libitum; 75: Restricted to 75% of the ad libitum intake; 1D: Free access to the feeder during all the day (24h/24); 2D: Access to the feeder 18 hours per day (between 16h30 and 10h30); Non significant (NS) : P> 0.05; Significant (S) : P < 0.05.

During the whole restriction period (32-63 days), there was no significant effect of the level of feed restriction in the feed conversion efficiency. However, the intake level improved the feed conversion between 42 and 63 days (-5.3%, P<0.05). Gidenne et al. (2003) have already reported a non significant of the level of intake in the feed conversion efficiency once, during the restriction period, the growth reduction is proportional to the reduction of the daily feed intake which leads to a similar feed conversion ratio between restricted and non-restricted rabbits. Reversely, Ledin (1984) and Perrier (1998) observed a deterioration of the feed conversion efficiency during the restriction period, while Boisot et al., 2003 reported that a low level of intake, during the restriction period, improves significantly the feed conversion efficiency (-4.2 and -7.6% for animals having 80 and 60% of the ad libitum intake). During the realimentation (63-70 days), there is a favourable effect of the feed restriction on feed conversion (-36.3%, P<0.001). This confirms the results obtained by previous studies (Ledin, 1984; Perrier, 1998; Boisot et al., 2003; Gidenne et al., 2003)
that reported an improved feed conversion during the realimentation period in restricted-realimented rabbits compared with those fed continuously *ad libitum* (between -113. and -34.8%). However, Foubert *et al.* (2008) did not find significant differences concerning the feed conversion efficiency in continuously or restricted-realimented rabbits. Concerning the whole fattening period (32-70 days), there was a significant effect (-8.8%, P<0.001) of the level of feed restriction in the feed conversion. Gidenne *et al.* (2003) have already reported a positive linear relationship between the level of intake and the feed conversion, during all the fattening period. In addition, other authors also reported a significant favourable effect of level of feed restriction in the feed conversion in the total fattening period: -13.7 and 17.9% for a level of intake of 80 and 60% of the *ad libitum*, reported by Boisot *et al.*,(2003); and, -8.4% for a level of intake correspondent to 70% of the *ad libitum*, referred by Foubert *et al.* (2008). Nevertheless, Ledin (1984) reported that in the entire growth period, the feed conversion was similar for the restricted-realimented and continuously *ad libitum* animals because the differences in the feed conversion efficiency in both periods (restriction and realimentation) tended to cancel each other, while Perrier (1998) found significant differences, but just for animals having a level of intake of 50% of the *ad libitum*.

Respect to the time for access to the feeder, it was observed a significantly better feed conversion from 32 to 42 days for animals having a reduced access to the feeder, and a reverse effect from 42 to 63 days. Indeed, from 32 to 42 days, for a similar daily feed intake, animals having a reduced access to the feeder presented a higher daily weight gain (+9.2%, P=0.05). While between 42 and 63 days, for a similar daily feed intake, animals having a reduced access to the feed had a lower daily weight gain (-11.2%, P=0.01). Accordingly, no significant effect of the time for access to the feeder was found for the whole restriction period. Foubert *et al.* (2007) reported that, during the restriction period, animals having access to the feeder during 6 or 8 hours per day showed a better feed conversion (-6.6 and -4.4%, respectively), while animals having access to the feeder 10h/day had a similar feed conversion than animals with free access to the feeder 24h/24. Besides, Matics *et al.* (2008) reported better feed conversion values (between -5.5 and -11.3%), during the first 4 weeks (28-56 days) of the restriction period (28-63 days) for animals having a reduced time for access to the feeder (9, 10, 12 or 14 hours between 4-5, 6-7, 7-8 or 8-9
weeks of age). During the realimentation period, no significant effect of the time for access to the feeder was found in the feed conversion. Matics et al. (2008) reported as well a non significant effect of the time for access to the feeder on the feed conversion during the realimentation period. Reversely, Foubert et al. (2007) referred that the feed conversion ratio was significantly improved with the reduction of the time to access to the feeder during the realimentation period (respectively, -20.7, -16.7 and -14.1% for 6, 8 or 10 hours/day of access to the feeder). Respect to the whole fattening period, no significant effect of the time for access to the feeder on the feed conversion was found. This is not in accordance with the findings of Foubert et al. (2007) and Matics et al. (2008). Both authors referred that the feed conversion ratio was significantly improved with the reduction of the time to access to the feeder during the entire fattening period: according to Foubert et al. (2007), -6.9, -4.9 and -2.4% for animals having access to the feeder during 6, 8 or 10 hours/day, respectively; and, according to Matics et al. (2008), -2.7% for animals having a reduced access to the feeder.

2.6. Effect of the level of feed restriction and time for access to the feeder in the animals’ health status

The tables 12 and 13 represent the mortality and morbidity occurred during the experimental period, respectively.

Taking into account the very low number of animals per group (12), it is not correct to perform a statistical analysis of the obtained data. However, when taking in account just the effect of the level of feed restriction, it was found that a low level of feed intake didn’t affect significantly the rabbits’ mortality. Perrier (1998) have already reported that, at weaning age, rabbits could be subjected to a feed restriction (~30% and ~50% of the ad libitum intake level) period without compromising their viability. It confirms as well the results obtained later by Tumova et al. (2002) and Foubert et al. (2008), where a feed restriction (50 or 65 g/day/rabbit and ~30% of the ad libitum intake level, respectively) did not affect mortality. Nonetheless, Boisot et al., (2003) and Gidenne et al. (2003) suggested that a feed restriction can be interesting to reduce post-weaning digestive
disorders and that a reduction of the intake of at least -20% of the *ad libitum* level is necessary to reduce mortality and morbidity in growing rabbits.

Table 12: Mortality according to periods of age

<table>
<thead>
<tr>
<th>Periods of age (days)</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1D100</td>
</tr>
<tr>
<td>32-42</td>
<td>-</td>
</tr>
<tr>
<td>42-63</td>
<td>3/12*</td>
</tr>
<tr>
<td>32-63</td>
<td>3/12</td>
</tr>
<tr>
<td>63-70</td>
<td>-</td>
</tr>
<tr>
<td>32-70</td>
<td>3/12</td>
</tr>
</tbody>
</table>

* Number of animals dead and individual number in parenthesis.

A relatively high number of rabbits died, due to an infection with colibacillosis (symptoms = strong diarrhoea). It must be remembered that no antibiotic treatment was used in this trial which can explain the number of dead animals observed during all the experimental period.

Table 13: Morbidity according to periods of age

<table>
<thead>
<tr>
<th>Periods of age (days)</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1D100</td>
</tr>
<tr>
<td>32-42</td>
<td>-</td>
</tr>
<tr>
<td>42-63</td>
<td>-</td>
</tr>
<tr>
<td>32-63</td>
<td>-</td>
</tr>
<tr>
<td>63-70</td>
<td>-</td>
</tr>
<tr>
<td>32-70</td>
<td>-</td>
</tr>
</tbody>
</table>

* Number of animals morbid and individual number in parenthesis.

2.7. Effect of the level of feed restriction and time for access to the feeder on the digestibility

According to the table 14, the interaction between the level of feed restriction and time for access to the feeder was not significant whatever the nutrient.
Table 14: Effect of the level of feed restriction and time for access to the feeder on the digestibility of the growing rabbit (between 49 and 53 days old)

<table>
<thead>
<tr>
<th>Component</th>
<th>Level of feed intake (%)</th>
<th>Time for access to the feeder</th>
<th>CV%</th>
<th>Pr&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>75</td>
<td>1D</td>
<td>2D</td>
</tr>
<tr>
<td>Dry matter</td>
<td>60.7</td>
<td>63.8</td>
<td>62.0</td>
<td>62.5</td>
</tr>
<tr>
<td>Organic matter</td>
<td>59.7</td>
<td>62.7</td>
<td>61.0</td>
<td>61.4</td>
</tr>
<tr>
<td>Crude protein</td>
<td>70.1</td>
<td>76.2</td>
<td>73.2</td>
<td>73.2</td>
</tr>
<tr>
<td>NDF</td>
<td>21.7</td>
<td>25.8</td>
<td>23.1</td>
<td>24.5</td>
</tr>
<tr>
<td>ADF</td>
<td>14.5</td>
<td>17.3</td>
<td>15.6</td>
<td>16.1</td>
</tr>
<tr>
<td>Hemicelluloses</td>
<td>32.5</td>
<td>38.6</td>
<td>34.3</td>
<td>36.7</td>
</tr>
<tr>
<td>Cellulose</td>
<td>18.3</td>
<td>21.5</td>
<td>19.2</td>
<td>20.6</td>
</tr>
</tbody>
</table>

100: *Ad libitum*;
75: Restricted to 75% of the *ad libitum* intake;
1D: Free access to the feeder during all the day (24h/24);
2D: Access to the feeder 18 hours per day;
Non significant (NS) : P> 0.05; Significant (S) : P < 0.05.

The effect of the intake level on feed digestibility (measured after 17 days of adaptation) was significant whatever the nutrient, which is in accordance with the findings of Di Meo *et al.* (2007) that referred that the apparent digestibility of nutrients was always higher for restricted-fed rabbits. The faecal digestibility of dry matter, organic matter and ADF was about 3 units higher in restricted animals, while for crude protein this effect was greater (+6.1 units). This confirms the results published by Xicatto and Cinetto *et al.* (1988), where a feed restriction (restricted to 65% or 45% of the *ad libitum*) caused a significant increase in the digestibility of dry matter (+2.1 or +4.9 units, respectively), organic matter (+2.2 or +5.1 units, respectively) and crude protein (+5.2 or 11.1 units, respectively). Later, in 1992, Xicatto *et al.* reported as well that a feed restriction led to a significant increase in the digestibility of dry matter, organic matter and crude protein. It confirms also the results obtained by Tumova *et al.* (2004) concerning the digestibility of the crude protein during the restriction period. Reversely, Feugier (2002) did not observe a significant effect of the level of feed restriction on the nutrients digestibility. However, these measures were made after 6 days of the beginning of the restriction period which is insufficient for the adaptation of the digestive system to the new level of intake.
Concerning the time for access to the feeder, it is possible to infer that with the exception of the digestibility of the NDF and hemicelluloses that was higher in the animals with a limited access to the feeder (-6 hours per day), the digestibility of all the other components was not significantly modified.

2.8. Effect of the level of feed restriction and time for access to the feeder in the faecal excretion rhythm

The figure 8 and table 15 illustrate the influence of the level of feed restriction and time for access to the feeder in the rabbits' daily faecal excretion.

![Figure 8: Faecal excretion pattern according to group](image)

* Quantity of hard faeces excreted in % of daily (24 h) excretion

In the group 1D100, the period of major faecal excretion is between the 15h and 5h, reaching its maximum value between the 17h-19h. Reversely, the faecal excretion is minimal between 5h and 15h, being zero between the 9h and 11h. This is in accordance with the findings of Lebas and Laplace (1974) in 8 weeks old rabbits. These authors observed a period of major faecal excretion between 17h and 1h, reaching a maximum value at 20h and a period between 9h and 16h where the faecal excretion was almost inexistent, being zero at 12h. Reversely, Ruckebusch
and Fioramonti (1976) reported that major faecal excretion takes place between 8h and 11h. However, these measures were made in adult rabbits what can explain the differences observed once, according with Carabâno and Piquer (1998), the age of the animals can alter the faecal excretion pattern. According to Lebas and Laplace (1974), the reduced faecal excretion observed between 5h and 15h can indicate that this period of time is dedicated to the caecotrophy.

<table>
<thead>
<tr>
<th>Period</th>
<th>Group 1D100</th>
<th>Group 1D75</th>
<th>Group 2D100</th>
<th>Group 2D75</th>
</tr>
</thead>
<tbody>
<tr>
<td>09h-11h</td>
<td>0</td>
<td>15.5</td>
<td>0</td>
<td>23.3</td>
</tr>
<tr>
<td>11h-13h</td>
<td>1.2</td>
<td>19.1</td>
<td>0</td>
<td>23.3</td>
</tr>
<tr>
<td>13h-15h</td>
<td>4.9</td>
<td>23.4</td>
<td>0.2</td>
<td>2.8</td>
</tr>
<tr>
<td>15h-17h</td>
<td>15.8</td>
<td>16.8</td>
<td>0.8</td>
<td>13.6</td>
</tr>
<tr>
<td>17h-19h</td>
<td>16.5</td>
<td>9.7</td>
<td>16.8</td>
<td>19.9</td>
</tr>
<tr>
<td>19h-21h</td>
<td>10.9</td>
<td>1.7</td>
<td>11.4</td>
<td>7.8</td>
</tr>
<tr>
<td>21h-23h</td>
<td>14.6</td>
<td>2.1</td>
<td>15.4</td>
<td>1.4</td>
</tr>
<tr>
<td>23h-1h</td>
<td>11.6</td>
<td>1.9</td>
<td>13.2</td>
<td>0.1</td>
</tr>
<tr>
<td>1h-3h</td>
<td>12.0</td>
<td>1.5</td>
<td>15.0</td>
<td>0</td>
</tr>
<tr>
<td>3h-5h</td>
<td>6.6</td>
<td>1.2</td>
<td>10.2</td>
<td>0.1</td>
</tr>
<tr>
<td>5h-7h</td>
<td>2.8</td>
<td>0.2</td>
<td>15.7</td>
<td>0.7</td>
</tr>
<tr>
<td>7h-9h</td>
<td>3.0</td>
<td>7.1</td>
<td>1.3</td>
<td>6.9</td>
</tr>
</tbody>
</table>

In the group 1D75, the rhythm of faecal excretion was different from the group 1D100. The major faecal excretion was observed between 7h-19h, reaching its maximum value between 13h-15h (when 4 in a total of 11 animals have ate all the food available, see table 16) as it can be observed in the table 15. After 13h-15h, the faecal excretion started to decrease gradually, reaching its minimum between the 5h and 7h in the morning, period that could be mainly reserved to the caecotrophy.

Generally, it is possible to observe that the reduction of the level of feed intake resulted in an earlier hour for faecal excretion (see figure 9) which is in accordance with the results of Lebas and Laplace (1975). Besides, it is also possible to observe that a low level of feed intake results in a less important faecal excretion during the night and consequently more important during the morning, when compared with an ad libitum feed intake level (see figure 9).
Table 16: Period of time in which the animals of the group 1D75 finish the meal (h)

<table>
<thead>
<tr>
<th>Animal</th>
<th>Group 1D75</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
</tr>
<tr>
<td>2</td>
<td>13h -15h</td>
</tr>
<tr>
<td>6</td>
<td>15h -17h</td>
</tr>
<tr>
<td>10</td>
<td>15h -17h</td>
</tr>
<tr>
<td>14</td>
<td>13 -15h</td>
</tr>
<tr>
<td>18</td>
<td>13 -15h</td>
</tr>
<tr>
<td>26</td>
<td>15h -17h</td>
</tr>
<tr>
<td>30</td>
<td>15h -17h</td>
</tr>
<tr>
<td>34</td>
<td>13 -15h</td>
</tr>
<tr>
<td>38</td>
<td>13 -15h</td>
</tr>
<tr>
<td>42</td>
<td>13 -15h</td>
</tr>
<tr>
<td>46</td>
<td>15h -17h</td>
</tr>
<tr>
<td>Average</td>
<td>13h -15h</td>
</tr>
</tbody>
</table>

Figure 9: Periods of the day for major faecal excretion*  

* > 80% for the groups 1D100, 1D75 and 2D100; > 40% for each excretion period in the group 2D75

The effect of reducing the time for access to the feeder (- 6 hours) also affects the faecal excretion rhythm. The faecal excretion pattern is more homogenous for the group 2D100 than for the group 2D75. In the group 2D75, there is a two-phase faecal excretion pattern (between 7h-13h and 15h-21h), while in the group 2D100, faecal excretion occurs in one-phase between 17h-7h. In the group 2D100, there is an important faecal excretion during night time (between 17h and 7h) and a less important faecal excretion rhythm in the morning compared with the group 1D100. The same tendency is observed when comparing the group 1D75 and 2D75: in the group 2D75, there
is a more important faecal excretion during night time and a less important faecal excretion in the morning than in the group 1D75 (see table 15 and figure 9).
IV. Conclusion and perspectives

A reduced intake level, between 32 and 63 days of age, induced a proportional reduction of the growth (-26.8%) and improved the feed digestibility whatever the nutrient. A short period (one week, between 63 and 70 days of age) with *ad libitum* level, after a period with restriction led to an important compensatory growth (+66%), associated to a better feed conversion (enhanced 36.3%). Nonetheless, despite the strong compensatory growth observed during realimentation, the animals did not compensate totally the growth retardation occurred during the restriction period (32 to 70 days: -8% of live weight and -11.8% of growth). Besides, a reduced level of intake resulted in an earlier hour for faecal excretion, being this one more significant during the morning and less important during night.

When the access to the feeder was not allowed for 6h, between 32 and 63 days, a two-phase excretion pattern was observed for animals having as well a reduced intake level. In addition, a reduced time for access to the feeder led to a more important faecal excretion during night and less important during the morning. During the post-weaning period, a slight improvement of fibre digestion (NDF and hemicelluloses), and a better feed conversion (-8.8%, between 32 and 42 days) were also found, but no changes for the growth or the feed intake were detected.

The results obtained here for individually caged rabbits should be confirmed for a collective caging system, to validate our conclusions about growth and feed conversion for commercial rabbitries. Furthermore, it would be of interest to analyse the effects of intake level and time for access to the feeder on the digestive health and carcass quality in the growing rabbit and, seek to modulate the length of the restriction period and/or the number of restriction periods in order to avoid strong growth delays, while keeping a good animal’s health status.
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