NUTRITION OF THE RABBIT

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Nutrition of the rabbit

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All rights reserved. No part of this work may be reproduced, used or transmitted in any form or by any means – graphic, electronic or mechanical, including photocopying, recording, or information storage and retrieval systems - without the written permission of the author.
Chapter 1. THE DIGESTIVE SYSTEM OF THE RABBIT

The digestive system of the rabbit is adapted to an herbivorous diet, including specific adaptations, from teeth to an enlarged caeco-colic segment with active microbiota, and the separation of caecal digesta particles allowing for caecotrophy.

The caecum and colon have relative importance when compared with other species.

1. Stomach

Stomach is always partially filled. It is continuously secreting and contrary to other mammals, the pH of the growing and adult rabbit’s stomach is always very acid (1.5 to 2.0). The capacity of the stomach is about 34% of the total capacity of the digestive system. After caecotrophy the fundic region of the stomach acts as a storage cavity for caecotrophes.

2. Small intestine

The small intestine (pH 7) is 3 m long, where the secretion of

- bile,
- digestive enzymes,
- buffers occurs.

It works similarly to other monogastric mammals. The small intestine in the site where the greater part of digestion and absorption take place. Digestibility at the end of the ileum accounts for 80-100% of the total dietary amino acid and starch digestibility.

3. Caecum

The caecum is the largest segment of the tract, 49% of the total capacity of the digestive tract. The caecal contents are slightly acid (pH 5.4-6.8), depending on microbial activity and feeding pattern.

4. Colon

Colon can be divided into two portions:

- the proximal colon (35 cm long) with fuses coli which acts as a pacemaker for the colon during the phase of hard faeces formation,
- the distal colon (80-100 cm long).

5. Age-related changes of the digestive system

Development of different segments of the digestive tract of the rabbit (weaned at 35 days) from 9 to 77 days of age.

a. The relative weight of empty segments with respect to body weight;

b. the relative weight of the segments and their contents with respect to body weight.

At birth, the stomach and small intestine are the main components of digestive tract.
From birth to 3 weeks of age, kits drink large amount of milk during a once-daily nursing, an amount that can reach 12% of their body weight. This explains the importance of the relative weight of the stomach.

At around 18 days of age kit begins to eat solid food and decrease its milk intake, and the caecum and colon develop faster than the rest of the digestive tract. From 3 to 7 weeks of age the caecum is filled by digesta and microbiota.
Chapter 2. CAECOTROPHY

- Intestinal contents enter the hindgut at the ileocecal-colonic junction, and uniformly disperse in the caecum.
- Contraction of the caecum moves material into the proximal colon.
- Peristaltic action moves large fibre particles (dashes) down the colon for excretion as hard faeces. Contractions of the haustrae of the colon move small particles (dots) and fluids backwards into the caecum.
- Small particles and fluids are thus separated from fibre.
- Soft faeces are excreted according to a circadian rhythm, which is the opposite to that of feed intake and hard faeces excretion.

1. Effect of age and lactation

Caecotrophy begins at 3-4 weeks of age, when rabbits begin to consume solid food.

Soft faeces production linearly increases with age, reaching a maximum at 9-11 weeks old (maximum growth, greatest feed intake).

From 11 to 19 weeks old soft faeces excretion stabilizes (growth rate decreases, feed intake increases slightly).

Lactating does show greater soft faeces production (higher feed intake).

Soft faeces contain greater proportions of protein, minerals and vitamin than hard faeces, while hard faeces are higher in fibrous components compared with soft faeces.

Nutrient supply through soft faeces is concerned, protein represents from 15 to 22% of the total protein intake.

It is high in essential amino acids: lysine, sulphus amino acids and threonine.

The importance of these amino acids depends on the efficiency of microbial protein synthesis.

Microbial activity is also responsible for the high content of K and B vitamins in soft faeces.
Chapter 3. RATE OF PASSAGE

- Stomach: 3-6 h
- Small intestine jejunal: 10-20 min ileum: 30-60 min
- Caecum: 4-9 h
- Mean retention time: 19 h (9-30 h)
  - Preventing caecotrophy: - 0-7 h (shorter)
  - Restricting feeding (50-60%): + 7-13 h (longer)
  - Increasing fibre content (22 → 40%): - 12 h (shorter)

Using pellet with smaller particle size: longer

1. Age-related changes in the function of digestive system

During the suckling period, the mucosal glands are able to produce enzymes to digest the main components of milk, while the maturity and functionally of pancreas are limited when compared to the adult.

In this period, gastric lipase represents most of the whole digestive tract, whereas this activity is not detectable in the 3-month-old rabbit.

Lactase activity is the highest until 25 days of age, and sucrase and maltase rise until reaching the adult level at 32 days.

The main proteolytic activity is also localized in the stomach of the young rabbit and its improvement decreases with age as proteolytic activity in the caecum, colon and pancreas increase.

The functionality of the digestive tract is limited from 21 to 42 days of age for amylase and lipase secreted by the pancreas and some enzymes of the gastric or intestinal mucosa, however protease activity is unclear. These findings are in line with the evolution of the pancreas.

Other enzyme activities that increase with the age of rabbit are those due to presence of microorganisms that will determine the ability of the rabbit to utilize fibre sources. Cellulase, pectinase, xylanase and urease are some of the main enzymes provided by the intestinal microflora.

2. Intestinal flora

The main genus of the microbial population in caecum of the adult rabbit is Bacteroides. Other genera such as Bifidobacterium, Clostridium, Streptococcus and Enterobacter complete this population.

During the first week of age, the digestive system of the rabbit is colonized by strict anaerobes, predominantly Bacteroides. At 15 days of age, the numbers of amylolytic bacteria seem to stabilize, whereas those of colibacilli decrease as the number of cellulolytic bacteria increase.

With changing the microbial population, the production of volatile fatty acids (VFAs) increases with age.

It is estimated that the rabbit obtains up to 40% of its maintenance energy requirements from VFAs production by fermentation in the hindgut.
Chapter 4. DIGESTION IN RABBIT

1. Starch digestion

Starch is a major reserve polysaccharide of green plants and the second most abundant carbohydrate in nature next to cellulose. Starch is found in nature as granules either in seeds, roots or tubers.

Starch is almost completely digested in the digestive tract of rabbits.

Starch digestion takes place mainly in the small intestine, and the most important enzyme involved is pancreatic amylase. Other enzymes: maltase, amyloglucosidase. Ileal digestibility of starch is between 95 and 99%. Amilase activity increases rapidly between weeks 2 and 7 of life, and is still increasing in 3-month-old rabbits, similarly the amyloglucosidase activity.

Maltase activity increases very rapidly between weeks 2 and 4 of life, but not afterwards.

Starch undigested in the small intestine is fermented by the microbiota in the caeco-colic segment to lactate and volatile fatty acids.

The effect of age seems to be very limited for the majority of starch sources e.g. (barley, wheat). However, faecal loses of starch greatly increase for maize and particularly for young rabbits.

2. Role of starch on digestive health

Dietary starch level do not greatly affect the mortality rate of the young rabbits, from the time they begin to consume feed until weaning. In fact, the consumption of milk represents an important part of nutrient intake and contributes to health status, thus explaining that the health status of the suckling rabbits is largely independent of the feed. The protective role of milk intake has been observed.

A former hypothesis suggested that an overload of rapidly fermentable carbohydrates in the large intestine increases the likelihood of digestive disorders in weaned rabbits.

Separating the effect of starch and fibre have revealed a low impact of starch intake on the incidence of digestive disorders in growing rabbits. Thus, the effects on digestive health are mainly linked to changes in fibre intake.

Fibre requirement should be increased at the expense of starch content.
Chapter 5. PROTEIN DIGESTION

1. Some characteristics of main protein sources

Proteins are macromolecules made up of long chains of amino acid residues covalently linked by peptide bonds to form polypeptide chains. Eight of amino acids are essential (isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine).

The nutritive value of protein is determined not only by its amino acid composition, but also its digestibility.

2. Protein and amino acid balance

The capability of different feedstuffs to meet the protein and amino acid requirements of rabbits depend on the nitrogen unite used. E.g. lucerne hay could represent 21% of the soybean meal value.

Crude protein and amino acid contents are the most common units used to express nitrogen requirements and the nutritive value of feedstuffs.

3. Faecal digestibility

Current nitrogen recommendation is expressed in apparent faecal digestible protein.

A negative correlation was found between faecal crude protein digestibility and acid detergent lignin.

An increase in the crude protein content of a feedstuff increases its faecal crude protein digestibility. The structure of proteins of feedstuffs with high crude protein content (e.g. legume feeds, lucerne leaves) is generally less resistant to digestion.

4. Ileal digestibility

The ileum is the last segment of the digestive tract where the amino acids can be absorbed. Therefore, ileal digestibility is considered to give a more precise estimation of the real availability of amino acids for animal protein synthesis in rabbits.

5. Nitrogen metabolism in the caecum

Residues of intestinal digestion and the urea recycled through the blood are potential substrates that allow caecal bacteria to obtain energy and nitrogen for growth.

At the end of the ileum, fibre is the main component of the digesta (about 70% of total DM), while nitrogen is second in importance (about 15% of total DM). In conventional rabbits the caecum contains more ammonia and true protein (enriched in essential amino acids) and lower quantities of endogenous components.

The proteolytic activity of caecal bacteria results in volatile fatty acids as energy-yielding compounds and ammonia production for growth.

Amino acids are only minimally absorbed in the last segments of the intestinal tract.

Ammonia production from protein and urea hydrolysis is partially used by caecal bacteria as the main substrate from protein synthesis.

The presence of condensed tannins may decrease the proteolytic capacity of caecal microorganisms.

The final result of bacterial activity in the caecum is a substantial change in amino acid composition of the protein that enters the caecum from the ileum.

The bacterial activity leads to enrichment in lysine, methionine and threonine.
Around weaning, the enzymatic capacity for protein digestion may be limited. The average values of apparent ileal crude protein digestibility are compared to faecal ones, only 71% of the total digested protein is digested at the ileum in young rabbits. This figure is lower than those reported in adult animals, which vary from 82 to 90%.

6. Soft faeces and protein digestibility

The main effect of soft faeces ingestion is protein reutilization.

The protein supply from the soft faeces is 18% of the total crude protein intake.

The highest values are associated with low-digestible diets that increase the flow of indigestible protein to the caecum. The lowest values are related to diets that supply small amounts of protein to the caecum.

The ingestion of soft faeces improves the diet’s apparent faecal digestibility, especially protein digestibility.

The ingestion of soft faeces enables rabbits to use part of the amino acids that will not be absorbed beyond the ileum for microbial protein synthesis.

Caecotrophy contributes to recycling 36% of the total protein excreted, which is mainly of bacterial origin. This protein is a good source of the most frequently limiting amino acids (methionine, lysine and threonine).

The main results of digestive process, which determine the amino acid composition of soft faeces with respect to diet composition, are

- the increase in the methionine to cysteine ratio as a consequence of the relatively high value of this ratio in bacterial protein,
- the decrease in arginine, histidine and phenylalanine.

Therefore, the amino acid supply from soft faeces from conventional diets does not seem to be enough to alter the dietary amino acid pattern in order to meet the essential amino acid requirements of rabbits.
Chapter 6. FAT DIGESTION

1. Chemical structure

The word „fat” is commonly misused to indicate all lipids.

Lipids can be divided into

- simple lipids, which do not contain fatty acids (FAs),
- complex lipids, which are esterified with FAs.

2. Chemical structure and physical properties of fats

Triglycerides can be considered „true” fats because they represent the most typical form of energy accumulation in animal and vegetable organisms. Only these lipids have real nutritional importance. Triglycerides are the highest energy-yielding components of feeds, yielding an average of 2.25 times more energy than other components (i.e. protein or starch).

The physical, chemical and nutritive properties of triglycerides depend on the characteristics of their FAs:

- the number of carbon atoms
  - Short-chain FAs formed to two (C2) to eight (C8) carbon atoms,
  - medium-chain FAs have 10-16 carbon atoms,
  - long-chain FAs have > 18 carbon atoms (up to 22-24).
- the number and position of unsaturated bonds (double bonds):
  - saturated FAs (SFAs) contain only single (saturated) bonds between carbon atoms,
  - unsaturated FAs (UFAs) present one or more double (unsaturated) bonds:
    - monounsaturated FAs (MUFAs) with only one double bond (e.g. oleic acid, C18:1),
    - polyunsaturated FAs (PUFAs) with two (e.g. linoleic acid, C18:2) or more (up to six) double bonds.

Animals need an adequate quantity of essential FAs in their diets, namely n-3 FAs and n-6 FAs. They are primarily represented by

- linoleic acid (C18:2, n-6), which is essential for the synthesis of arachidonic acid (C20:4, n-6), the precursor of prostaglandins and prostacyclins (reproductive function) or thromboxanes (haemostasis function),
- linolenic acid (18:3, n-3), which is essential for the synthesis of eicosapentaenic acid (C20:5, n-3) the precursor of several compounds essential for heart, retina and brain functions, and the immune systems.

The low n-6 to n-3 FA ratio in foods is beneficial in reducing the incidence of cardiovascular and thrombotic diseases in humans.

The degree of unsaturation affects fat stability because double bonds are easily oxidized which give fat and feed their typically rancid odour. The rate of oxidation rises as the number of unsaturated bonds increases: linolenic acid (C18:3) is oxidized ten times more rapidly than linoleic acid (C18:2), which is oxidized ten times more rapidly than oleic acid (C18:1).

3. Fats in rabbit feeds

The triglycerides usually present in rabbit feed and pure vegetable and animal fats contain primarily medium – or long-chain FAs (C14-20), with C16 and C18 FAs being most common.
Traditionally, rabbit feeding is based on low- or moderate-energy diet. Pure fats or oils are therefore not added and the dietary crude fat content does not exceed 3-3.5%, on average.

The addition of limited amount of fats (1-3%) to rabbit diets is rather common under intensive rearing system. In breeding does, this increases dietary energy concentrations and stimulates energy intake by the female, who experiences a severe energy deficit during lactation.

In weaning rabbits, the dietary addition of fat may improve body condition, stimulate development of immune system and improve health.

In growing rabbits, fat supplementation may favorably change the FA profile and the nutritional value of rabbit meat.

4. Triglyceride digestion and utilization

Triglycerides are emulsified and than hydrolyzed by lipolytic enzymes before being finally absorbed in the small intestine.

In different species (human, pig, rat, cattle), the digestive process in suckling animals begins in the stomach by pre-duodenal lipases. In suckling rabbits, gastric lipases account for most of the lipolytic activity.

After weaning, triglycerides from solid feed require emulsification, and therefore fat digestion occurs only in the small intestine. Fat emulsification is promoted by bile salts separated by the liver. Bile salts mix with fat droplets, breaking them down into minute globules that can be easily hydrolysed by pancreatic lipase and other lipolytic enzymes. The enzymatic hydrolysis of triglycerides leads to the separation of glycerol, free FAs and monoglycerides, which remain emulsified with bile, forming microscopic micelles.

The micelles move to the microvilli of the duodenum and jejunum, which absorb the glycerol, free FAs and monoglycerides.

Fat absorption is passive (i.e. non-energy-consuming process).

When absorbed into enterocytes, glycerol and short-chain FAs (C<12) go directly into the blood, where they circulates as non-enterified FAs.

Monoglycerids and medium- and long-chain FAs (C>12) are re-synthesized as triglycerides.

Long-chain FAs that are enterified in the triglycerides of chylomicrons can be metabolized as energy sources or either incorporated directly into fat tissue or transferred unchanged to the milk. For this reason, the composition of the dietary fat can significantly influence fat characteristics in the rabbit carcass or the FA composition of the milk.

FAs that are not digested can pass through the lowest part of gut and be excreted in the faeces as soaps or enter the caecum, where UFAs are hydrogenated by the caecal microflora.

5. Effect of the level and source of fat

Lipid digestibility depends primarily on the level and source of added fats.

The ether extract digestibility (EEd) of a non-added-fat diet, which contains 2.5-3.0% structural lipids are rather low (45-65%), while the EEd of added-fat diets is higher because of the higher digestibility (85-95%) of pure fats.

The increase in EEd with higher levels of dietary fat could also be ascribed to a reduction in dry matter (DM) intake. This usually occurs when feed of a high dietary energy value is given, as a consequence of the chemostatic regulation of appetite. The decrease of DM intake is associated with a lower transit of digestion and consequently leads to increased digestion efficiency.

When the inclusion of fat is high (e.g.>6%) EEd may decrease probably because both digestive efficiency and microbial activity in the excessive fat.
The differences observed in EEd among various sources of fats are mostly attributed to their molecular structure and chemical bounds. The fat contained in conventional raw materials is linked to plan structures and is therefore poorly digested.

Pure added fats are much more easily digestible, and this is also true for the fat contained in heated (or extruded) full-fat contained in heated (or extruded) full-fat oil seeds, such as full-fat soybean or golden flax seed.

More saturated fats (e.g. beef tallow, lard) are less digestible than unsaturated fats (e.g. sunflower or soybean oil), probably because the latter are more easily emulsified and therefore digested in the gut.

6. Effect of age

6.1. Suckling rabbits

Rabbit milk contains a high quantity of lipids (10-15%) that are easily digested and absorbed by suckling rabbits, which show high gastric lipase activity:

- EEd of milk is 97%
- EEd of pelleted food is 74%

6.2. Weaning rabbits

When kits begin to consume solid feed, fat digestion occurs in the small intestine.

Lipase activity in the total proteic extract of gastric mucosa decreases from 15 to 43 days of age and is quite low or nearly absent in older rabbits.

In contrast, the lipase activity of the pancreas, intestinal mucosa and small intestinal contents increases from 25 to 42 days of age. Similarly, lipase activity significantly increases in the colon of rabbits from 28 to 90 days of age.

6.3. Growing and adult rabbits

Comparing digestibility efficiency in growing rabbits and adult does fed a non-added-fat diet a significantly lower EEd in young rabbits was observed than that in adult rabbits (58 vs. 64%), but no differences between the sexes in growing rabbits or between physiological status (pregnant of non-pregnant) in adult does.
Chapter 7. FIBRE DIGESTION

Dietary fibre (DF) is the major fraction of rabbit diet, where it accounts for 40-50% of the total diet.

The importance of fibre is due to its influence on

- the rate of passage digesta and mucosa functionality,
- substrate for microbiota.

All of these factors are related to rabbit health and performance.

1. Plan cell wall and dietary fibre

Plan cell wall is formed of cellulose microfibrils (the backbone) embended in a mix of lignins, hemicelluloses, pectins and proteins.

Definition of dietary fibre:

“Dietary fibre is defined as the feed components resistant to mammalian endogenous enzyme digestion and absorption, and that can be partially or totally fermented in the gut.”

“Dietary fibre is the indigestible or slowly digested organic matter of feeds that occupies space in the gastrointestinal tract, mainly insoluble fibre. It excludes rapidly fermenting and soluble carbohydrates (e.g. oligosaccharides, fructans).”

2. Biochemical characteristics of dietary fibre

There are two main groups of dietary fibre components according to their location, chemical structure and properties:

- Cell wall components:
  - water-soluble non-starch polysaccharides (e.g. pectic substances)
  - water-insoluble polymers: lignin, cellulose, hemicellulose and pectic substances.
- Cytoplasm components:
  - oligosaccharides, fructans, resistant starch and mannans.

3. Methods for estimating the dietary fibre content of animal feeds

Dietary fibre can only be truly measured by the digestive process of the animal.

The crude fibre method is highly reproducible, quick, simple, cheap and frequently used all over the world.

This method is not very useful in explaining the effects excreted by fibre on the animal.

The main alternative to the crude fibre method is the sequential procedure of Van Soest.

The NDF method was designed to isolate insoluble dietary fibre components in plan cell walls by using a hot neutral detergent solution-cellulose, hemicelluloses and lignin- as the majority of pectin substances are partially solubilized.

The ADF method isolates cellulose and lignin, the worst digested fibrous fractions, using a hot acid detergent solution. It is designed to be performed after NDF analysis, as pectins are retained when it is performed directly.
The main advantage of this sequential methodology is that it is possible to obtain an approximate estimation of

- lignin (ADL),
- cellulose (ADF-ADL),
- hemicellulose (NDF-ADF).

Dietary insoluble fibre can be estimated by using near infra-red (NIR) technology.

NIR technology has demonstrated usefulness in predicting dietary DM, protein, fat, starch and even digestible energy value.

ADF is the only fibre fraction that can be adequately estimated by this technique, whereas both NDF and ADL are estimated with lower precision.

4. Precaecal digestion of fibre

Traditionally, fermentation of dietary fibre has been considered to be a post-ileal activity of the endogenous microbiota. However there is evidence that some components of structural carbohydrates are degraded prior to entering the caecum of rabbits.

The extend of precaecal fibre digestion in rabbits varies:

- from 7 to 19% for crude fibre
- from 5 to 43% for NDF
- from 0 to 37% for NSP (non-starch polysacharides)

Around 40% of total digestible fiber is degraded before the caecum.

5. Caecal digestion of fibre

5.1. Microbial activity

Most of the effects exerted by fibre on the rabbit digestive physiology depend on its hydrolysis and fermentation by the digestive microbiota.

The caecal microbial population secretes enzymes capable of hydrolysing the main components of dietary fiber. Greater enzymatic activity for degrading pectins and hemicelluloses than for degrading cellulose has been detected.

5.2. Fermentation pattern

Volatile fatty acids (VFAs):

- VFAs are the main products of carbohydrate microbial fermentation.
- VFAs are rapidly absorbed in the hindgut and provide a regular source of energy for the rabbit.
- The caecal VFA profile is specific to the rabbit, with a predominance of acetate, followed by butyrate and then propionate.

Caecal pH:

- Caecal pH gives an estimation of the extent of the fermentation.
- It decreases with the inclusion of ingredients such as sugar beet pulp, soy hulls and lucerne in the diet.
- The opposite occurs with cereal straw and grape-seed meal.
Chapter 8. ENERGY AND PROTEIN
METABOLISM AND REQUIREMENTS

1. Energy units

• Joule (J) is the international unit used to measure all forms of energy including feed energy.

• The standard calorie (cal) is commonly used in practice may be converted in to J by multiplying by 4.184.

In the nutrition of rabbits the following energy parameters are used to express energy requirements and the nutritive value of feeds:

• gross energy (GE),

• digestible energy (DE),

• metabolizable energy (ME),

• net energy (NE).

Gross energy (GE) is the quantity of chemical energy lost as heat when organic matter is completely oxidized.

GE content depends on the chemical composition of the organic matter. The caloric values of the individual components are:

• crude protein: 22-24 kJ/g,

• ether extract: 38-39 kJ/g,

• carbohydrates: 16-17 kJ/g.

The GE concentration in complete diets or raw material does not provide any useful information on the availability and utilization of dietary energy by the animal.

Digestible energy (DE) can be measured in vivo by substracting the quantity of recovered in the faeces from GE (the energy of undigested nutrients).

In compound feeds for rabbits, the DE usually varies from 50 to 80% of the GE.

Metabolizable energy (ME) is calculated from DE by substracting the energy loss associated with urine and intestinal fermentation gases (methane).

Net energy (NE) is actually utilized by the animal for maintenance and productive purposes. It is the most precise estimation of feed energy value and animal energy requirements: NE for maintenance, growth, milk production etc.

ME is more precise than DE, DE and ME are closely correlated and ME can be easily estimated as 95% DE.

2. Energy metabolism and requirements

Several factors influence the energy metabolism and consequently the energy requirements of rabbits:

• body size, which depends on breed, age and sex,

• vital and productive functions, such as maintenance, growth, lactation and pregnancy,

• environment (ie. temperature, humidity, air speed).

Appetite in rabbits is mostly regulated by a chemostatic mechanism.
Growing rabbits naturally consume sufficient feed to meet their energy requirement. Reproducing does have high energy requirement for pregnancy, lactation and concurrent pregnancy and lactation that are often not covered by an adequate voluntary intake. 

Voluntary energy intake is proportional to metabolic live weight (LW0.75). In growing rabbits it is 900-1000 kJDE/kgLW0.75 and chemostatic regulation appear only with a DE concentration in the diet of > 9 MJ/kg. Below this level a physical-type regulation is prevalent, which is linked to the filling of the gut with dietary material.

2.1. Voluntary feed and energy intake

Reproducing females can ingest on average 1100-1300 kJDE/day/kgLW0.75 during lactation, with the lowest value recorded by primiparous females, and have a different energetic limit of chemostatic regulation compared to growing rabbits. An increase in DE concentration > 9-9.5 MJ/kg permits a further increase in the daily energy intake of lactating females. In these animals, the regulation limit probably varies by around 10.5-11 MJ/kg. It depends on the dietary energy source, tending to be higher in added-fat diet than in high-starch diets.

2.2. Energy requirements for maintenance

DEm may be proposed as

• 430 kJ/day/kgLW0.75 for growing rabbits,
• 400 kJ/day/kgLW0.75 for non-reproducing does,
• 430 kJ/day/kgLW0.75 for pregnant does,
• 430 kJ/day/kgLW0.75 for lactating does,
• 470 kJ/day/kgLW0.75 for concurrently pregnant and lactating does.

2.3. Energy requirements for growth

The growth-response curve shows that the maximum average daily growth is achieved when the dietary DE concentration is about 10-10.5 MJ/kg. An increase in the level of dietary energy intake also affects body gain composition and the partition of energy retained as protein and fat.

2.4. Pregnancy

During early and mid-gestation (0-21 days), the LW increases similarly to that of non-pregnant does. During late pregnancy (21-30 days), the empty body weight decreases as a result of protein and fat losses and a transfer of energy to the rapidly growing fetuses. At the same time non-pregnant does continue to gain weight and retain body energy, primarily in the form of fat. The transfer of energy from the body of does to the fetuses leads to an energy deficit that is especially concentrated in the last 10 days of pregnancy.

2.5. Lactation and concurrent pregnancy

The energy output during lactation is exceptionally high in rabbits, compared to other species:

• milk production: 200-300 g/day
• concentrations in DM: 30-35%
• protein: 10-15%
• fat: 12-15%

The caloric value (8.5 MJ/kg) is about 2.9 times higher than that of cow milk (2.97 MJ/kg).
If the daily excretion of energy as milk is expressed in terms of metabolic weight, however, the average milk energy output is higher in rabbits than in cows.

- a 4 kg doe producing 250 g milk/day excretes 751 kJE milk/day/kgLW^{0.75}
- a 800 kg cow producing 25 kg milk/day excretes only 612 kJE milk/day/kg LW^{0.75}

The dietary DE is utilized very efficiently by lactating does (60-70%).

The efficiency of utilization of energy retained in the doe’s body reserves for milk production is 81% in lactating does and 76% in lactating and pregnant does.

2.6. Energy and material balance during reproduction

The significant energy excretion through milk in lactating does is not completely compensated by voluntary DE intake especially in primiparous does. This causes a consistent deficit in both body tissues and energy.

During the first pregnancy, DE intake decreases from 600 to 650 kJ/day/kg LW^{0.75} in the first 24 days until 400-450 kJ/day/kg LW^{0.75} in the last 5 days, due to the increasing volume of fetuses in the abdomen. On the day of kindling the doe ingests only a small amount of feed.

Voluntary DE consumption is much higher in lactating females. The highest values are recorded by multiparous does. After weaning, does quickly decrease their energy intake.

During lactation, the doe’s body is subjected to a marked reduction in energy reserves following the mobilization of fat deposits.

The emergence of high-performance hybrid lines with higher nutritional needs, but that are unable to ingest sufficient dietary energy, has increased rabbit doe susceptibility to the energy deficit.

2.7. Nutritional strategies to reduce energy deficit

2.7.1. Feeding young does

Young does should face their first mating pregnancy and lactation with and adequate body energy condition to support the high nutritional requirement of reproduction.

From weaning to 11-12 weeks of age feeding programmes are similar to those of rabbits kept for meat production.

From puberty to first mating (16-18 weeks of age), the feeding programme should aim to permit correct morphologic and reproductive development and avoid over fattening.

At 17 weeks of age, breeding rabbits given ad libitum access to diet containing 10 MJ DE/kg may reach about 3.4 kg LW and 13% body fat. This condition may be excessive if the further fattening during pregnancy or the rapid over fattening in 2-3 weeks in case of failure of pregnancy are considered.

Feeding restriction (80-90% of ad libitum intake) may be applied to young does for different periods before mating to obtain a target weight at insemination.

In restricted does, flushing with a lactation diet given ad libitum is usually performed 4-7 days before the first insemination to avoid a reduction in sexual receptivity at this time.

Feed restriction can continue also in the first part of pregnancy, especially when LW exceeds target weight, while ad libitum feeding with a lactation diet is recommended during the last 2 weeks of pregnancy to take into account increasing pregnancy requirements.

In young does, feeding restriction may reduce voluntary feed intake in the following pregnancy and lactation and accentuate the risk of a negative energy balance between reproductive cycles.
The administration of high-fibre, low-energy diets to young females before the first mating increases voluntary feed intake during growth and pregnancy, and partially decreases the body fat and energy deficit at the end of first lactation.

2.7.2. Feeding reproducing does

During early pregnancy, increasing dietary DE concentration usually reduces DM intake and does not change DE intake.

During the last week of pregnancy, voluntary feed intake is limited by physical intake capacity.

During lactation, feeding high digestible diets increases DE intake, especially when added-fat diets are used in comparison with high-starch diets.

A higher dietary energy supply determines an increase of milk production, impairing its potential effect on body condition both in primiparous and multiparous does.

2.7.3. Parity order

The occurrence of doe body energy deficit has been largely proven during the first lactation.

Multiparous does are usually considered capable of ingesting higher amount of feed therefore of achieving body energy and protein equilibrium. Substantial body fat and energy mobilization has been observed in multiparous lactating does. Significant increases (5-15%) in feed intake from the first to the second and from the second to the third kindling, followed by lower but not significant increases for successive parities were described.

In does submitted to a semi-intensive rhythm and traditional weaning, the body energy deficit no longer appears in females after their third kindling.

3. Management strategies

3.1. Parity order

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3.2. Breeding rhythm

On commercial farms, rabbit does are usually mated on a fixed day:

- intensive rhythm: 3-5 day PP (post partum),
- semi intensive rhythm: 10-12 or 17-19 days PP,
- extensive rhythm: 24-26 days PP.

This determines exact theoretical intervals between two kindlings of 5, 6, 7 or 8 weeks.

Intensive PP insemination implies an excessive exploitation of the doe, which finally results in a reduction in reproductive performance and career length.

Extensive rhythms allow a too-low number of kindling per year and can cause doe over fattening, higher embryonic mortality and impairment of reproductive performance.
The most diffuse remating programme is the semi-intensive rhythm. This rhythm is a compromise between the doe’s need to recover energy between one reproductive cycle and the next and the economic demand of increasing the number of kits weaned per year.

The breeding system greatly affects the energy balance of lactating does, influencing both milk production and feed intake. Does submitted to intensive reproductive rhythms begin showing decreased milk production after 15-17 days of lactation, with a sharper decrease in the last week of pregnancy due to the exponential changes caused the imminent kindling that compromise milk production.

Lengthing the interval between kindlings prolongs the dry period and should permit body energy reserves to recover.

In primiparous does, a severe body energy deficit has been observed within the first and second kindlings with insemination at 12 days PP (-26% of initial body energy content).

When multiparous does were submitted to early weaning (21 or 25 days), the body energy deficit disappeared in those submitted to semi-intensive and extensive rhythms, but was severe in rabbits submitted to an intensive reproductive rhythm.

### 3.3. Litter weaning age

Under field conditions, kits are usually separated from their mother at around 32-35 days of age or even later.

The greatest interest in early weaning lies in the possibility of reducing the doe body energy deficit by

- shortening the lactation length (the period of energy deficit with body energy utilized for milk synthesis),
- prolonging the dry period (the period of energy surplus, with body energy restoration).

In does at their first, second and third kindling reducing weaning age from 32 to 21 days of age improved body energy balance (from -19% to -8% of the initial body energy content), but was unable to achieve equilibrium.

In multiparous does, weaning at 25 days did not prevent body energy deficit (-8% of the initial energy content), while weaning at 21 days resulted in a balance.

### 4. Protein units

Crude protein (CP) and apparent digestible protein (DP) are the most commonly used units, for which both requirements and raw material composition are largely available.

Rabbit have specific amino acid requirements and apparent faecal and true digestible amino acids would be more reliable units.

In practice, due to the chemostatic regulation of appetite in rabbits, nitrogen requirements are expressed in relation to dietary energy by the DP to DE ratio, which is directly correlated to body nitrogen retention and excretion.

### 5. Protein units and their measurement

#### 5.1. Growth requirement

DP requirements vary according to the growth ratio. The EB protein concentration changes:

- at birth: 12%
- at weaning (35d): 17%
- at 10-12 weeks of age: 20%

Afterwards, the body protein concentration is quite constant (20% in EBW, 13% in LW). The efficiency of utilization of DP intake for growth is estimated to be 56%.
Overall DP retention (RP/DPI) decreases linearly from 40% to 10% with increasing live weight, due to the increase in DP used for maintenance.

### 5.2. Pregnancy and lactation requirement

During the first pregnancy rabbit does retain protein in their body in the early gestation (0-21d), while they transfer some protein from their body to the rapidly growing fetuses in the late period of pregnancy (21-30d). This is due to the exponentially increasing protein requirements of the fetuses and the intense fetal protein turnover, which has been shown to be five times higher than that of maternal tissue. The efficiency of DP utilization for fetal protein synthesis is 42 and 46% in lactating and concurrently lactating and pregnant does, respectively.

In lactating does, the coefficients of utilization of DP and maternal body protein for milk protein are estimated at 77 and 59%, resp.

The high milk production and high milk protein concentration (11-13%) accounts for the high protein requirement for milk synthesis.

In concurrently pregnant and lactating does that are subjected to an intensive reproductive rhythm, limited body protein losses (5-10% of initial content) have been found.

### 6. DP to DE ratio

The dietary protein levels recommended for growing rabbits, young females and bucks range from 15 to 16% CP and from 10.5 to 11% DP.

In reproducing does, CP from 17.5 to 19% and DP from 12.5 to 13%.

These values correspond to a DP to DE ratio of 10.5-11.0 g/MJ for young rabbit and bucks and 11.5 to 12.5 g/MJ for reproducing does. The higher values are recommended for does under intensive breeding rhythms.

### 7. Amino acid requirement

The amino acid supply through caecotrophy consider adequate to support essential amino acid requirements. In rabbits fed conventional diets, the contribution of soft faeces to total CP intake is only 15-18%.

In lactating does, the contribution of caecotrophy has been found to make up

- 17% of the supply of sulphur aminoacid,
- 18% of lysine
- 21% of threonine.

The most limiting essential amino acids in rabbit diets are methioine, lysine and threonine.

### 8. Protein retention and nitrogen excretion

In highly populated areas animal waste can represent a potential contaminant of water and soil. The European directive 93/676/EC aims to prevent or reduce the nitrate pollution of surface and underground water, and ask each member to state reference values for nitrogen excretion of all livestock as well as to define feeding and management strategies to control environmental pollution.

The farm nitrogen balance of rabbits can be calculated as the difference between the nitrogen input (dietary nitrogen) and the nitrogen output (produced rabbits) at the farm.

Various factors can affect farm nitrogen balance.

#### 8.1. Dietary protein level
8.1.1. Fattening rabbits

Nitrogen excretion is strictly dependent on dietary CP level. In fattening rabbits, once the limiting amino acid requirements are satisfied by synthetic amino acid supplementation, dietary CP may be reduced to 17%, therefore decreasing nitrogen excretion without impairing productive performance.

Daily weight gain is impaired only at <13.8% CP (-9%), but nitrogen excretion is reduced by 38%.

8.1.2. Reproducing does

In reproducing does, protein and amino acid requirement are largely satisfied by the current lactation diet.

A reduction of dietary CP during lactation until 17% does not affect doe reproductive performance, milk yield and litter growth.

Taking into account that the lactation diet represents about a third of the total feed consumed in a closed-cycle farm (reproduction and fattening sectors), advantages in terms of reducing nitrogen excretion are of great importance.

8.2. Dietary energy level and DP to DE ratio

High-fibre, low-starch diets with low DE concentration have been largely used in the last decade to reduce the risk of digestive diseases.

When lowering DE concentration, feed intake increases and, if dietary CP concentration remains unchanged, the DP to DE ratio and nitrogen intake increase. Since growth rate is not modified and nitrogen retention remains constant, nitrogen excretion increases.

As an example, when DE concentration decreases from 10.5 to 8.8 MJ/kg and dietary CP concentration maintained at 15% with 70% digestibility, the DP to DE ratio increases from 10 to 12 g/MJ. The body nitrogen retention remains unchanged while daily nitrogen excretion (faecal + urinary) increases by 20%.

8.3. Numerical productivity of rabbit does and slaughter weight

Numerical productivity (i.e. number of rabbits produced per doe per year) directly affects the amount of excreted nitrogen on the farm and is in its turn influenced by several factors.

The number of rabbits produced per doe per year:

- 35-40 in does submitted to extensive rhythms (post weaning mating).
- 45-50 in those undergoing intensive or semi-intensive rhythms (mating 5-12 days PP).

In a closed-cycle farm, which both reproductive and fattening sectors, nitrogen excretion can be referred to the reproducing doe, including its offspring produced during a year. In this case, excreted nitrogen per doe per year depends on numerical productivity and the slaughter weight of fatteners.

A reduction in the average CP level from 17 to 16% permits a decrease of that nitrogen excretion by 8-10%.

If the nitrogen excretion values divided by the number of rabbits produced per year, excreted nitrogen decrease.

From 150 to 127 g per rabbit of 2.25 kg LW as the doe numerical productivity increases from 35 to 50 rabbits produced per doe per year.

With rabbits sold at 2.75 kg LW, the nitrogen excreted varies from 241 to 185 g per rabbit as the doe numerical productivity increases.
Chapter 9. MINERALS

1. Mineral requirements of rabbits

Rabbit meat is

• poor in sodium
• rich in potassium and phosphorus

when compared to meat from other domestic species.

Compared with that from other mammals, rabbit milk is

• high in ash, especially in
  • calcium
  • phosphorous
  • sodium

This is not surprising since the bones of the newborn kits are immature at birth and need extensive mineralization.

2. Calcium (Ca)

Calcium is the main component of the skeleton. Over 98% of the total body calcium is present in bones and teeth. In addition, calcium plays a key role in heart function, muscle contraction, blood coagulation and electrolyte equilibrium in serum. Furthermore, the doe milk is rich in calcium.

Therefore, the dietary requirements for calcium are accepted to be greater for fast-growing young animals and rabbit does in late gestation or at the peak of milk production.

When compared to other domestic species, the metabolism of calcium in rabbit presents important differences:

• it is absorbed in direct proportion to its concentration in the diet, regardless of metabolic need and, therefore, blood levels of calcium rise with increasing intake,
• urine is the main route used by the rabbit to eliminate any excess.

High milk-producing does might suffer a syndrome similar to that of milk fever in dairy cows. During late gestation and early lactation, does may show a drop in calcium and other mineral levels in plasma that result in loss of appetite.

3. Phosphorous (P)

Phosphorus is a major constituent of the bones. It also plays an important role in energy metabolism.

A major factor influencing phosphorous availability from plant materials in non-ruminant animals is the presence of phytates complex. In the rabbit, phytase phosphorous is well utilized because of phytase production by the microorganisms of the caecum. Most of the phosphorous is recycled through soft faeces followed by caecotrophy and, therefore, should results in an almost complete utilization of phytate phosphorous.

There is growing interest in controlling the excretion of phosphorous through feed manipulation to reduce environmental pollution.

4. Calcium to phosphorous ratio
A dietary relationship of calcium to available phosphorous of 2:1 to 1.5:1 is widely accepted in practical feeding.

Rabbit milk maintains constant 2:1 calcium to phosphorous ratio throughout the lactation period.

For growing rabbits, the recommendations vary from 4 to 10 g for calcium and from 2.2 to 7 g for phosphorous.

Calcium and phosphorous requirement are higher for lactating does. Practical recommendations in doe feed vary from 7.5 to 15 g for calcium and from 4.5 to 8 g for phosphorous.

5. Magnesium (Mg)

Magnesium is a major component of the bones (70% of total body magnesium is in the skeleton) and also acts as a cofactor in many metabolism reactions. Deficiency produces poor growth, poor fur texture and fur chewing.

6. Potassium (K)

Potassium plays a key role in the regulation of the acid-base balance in organisms and is a cofactor in numerous enzymes.

Symptoms of deficiency include muscle weakness, paralysis and respiratory distress.

Potassium ion (K+) deficiency in rabbits might appear when diarrhea is present.

Ingredients used in rabbit diet are rich in K+ (e.g. soybean meal, lucerne, molasses).

7. Sodium (Na)

Sodium is involved in the regulation of pH and osmotic pressure.

Sodium is essential for the absorption of luminal nutrients such as glucose and amino acid.

8. Chloride (Cl)

Chloride is also involved in acid-base regulation.

The relationship between Na+, K+ and Cl- (the electrolyte balance) affects animal production, influencing resistance to thermal stress, leg score, kidneys function and incidence of milk fever.

9. Trace minerals

Trace minerals are defined as those elements required in mg per day and needs are expressed in mg/kg or ppm of the diet. The definition includes

- iron
- copper
- manganese
- zinc
- selenium
- iodine
- cobalt
- etc.
Iron is a major constituent of enzymes involved in oxygen transport and metabolism. Deficiency may result in impaired hemoglobin formation and anemia. Rabbits have sufficient iron reserves at birth, provided the doe has received a properly supplemented diet. Therefore, rabbits are not as dependent as piglets on an exogenous supply of iron for survival.

Most ingredients used in feed are rich in iron. Does fed the iron-supplemented diet produced more milk and had greater litter size and litter weight than controls.

Copper has role in energy and iron metabolism and hair formation. Deficiency will manifest as retarded growth, grey hair, bone abnormalities and anemia. The beneficial effects are more noticeable in young animals under poor sanitation status and the presence of digestive diseases.

Manganese acts as a coenzyme in amino acid metabolism. Deficiency results brittle bones and leg problems and reproductive failure.

Selenium: Diseases such as white muscle, liver degeneration and exudative diathesis and impaired reproduction and poor immunity have been associated with selenium deficiency. Role of selenium is closely linked to vitamin E. Selenium is constituent of the enzyme glutathione peroxidase which plays a role in the detoxification of peroxides formed during metabolic processes.

Feeding supplemental organic selenium (0.12-0.50 mg/kg) in fattening rabbits increases the selenium content of meat. Extra selenium supplementation has limited potential to improve the oxidative stability status of rabbit meat. Therefore, the rabbit is more dependent on vitamin E and less on selenium than other mammals in reducing the oxidation load on tissues.

Zinc is a component of numerous enzymes and is involved in the biosynthesis of nucleic acids and in cell division processes. High levels of zinc are recommended for reproduction and fur and hair production than for maintenance or meat production.

Iodine is a component of the thyroid hormones that regulates energy metabolism. Does are probably more sensitive to iodine deficiency than growing-fattening rabbits.

Cobalt: The only metabolic role currently accepted for cobalt is a component of vitamin B₁₂. Therefore, similar symptoms of deficiency are observed in case of cobalt or vitamin B₁₂. Rabbits depend on cobalt to produce vitamin B₁₂.
Chapter 10. VITAMINS

1. Vitamin requirement

Vitamins are defined as a group of complex organic compounds that are present in minute amount in natural feeds and are essential for nutrient metabolism and life.

Except for choline, vitamins are required in minute amounts and requirements are expressed a UI, mg/kg or ppm.

All vitamins have essential functions in the organism: most act as metabolic catalysis of organic process.

Vitamins are classified on basis of their solubility:

• vitamin A, D, E and K soluble in fat,
• all the others (B complex, vitamin C) are soluble in water.

Fat-soluble vitamins are absorbed with dietary lipids. In general, they are stored in the body (predominantly in the liver and fat tissues) in appreciable amounts.

Water-soluble vitamins are not stored but rapidly excreted, the exception being vitamin B₁₂. Both groups differ in their excretion pattern:

• fat-soluble vitamins are excreted primarily in faeces via the bile,
• water-soluble vitamins are excreted mainly through the urine.

A continuous supply is more important for water- those fat-soluble vitamins.

2. Fat-soluble vitamins

2.1. Vitamin A

Vitamin A is only found in ingredients of animal origin or synthetic supplement. Plants contain a series of precursors, the carotenoids, with variable vitamin A activity. In the rabbit β-carotene, the most important precursor of vitamin A found in vegetables, is converted into vitamin A in the intestinal mucosa. Vitamin A participates in numerous metabolic reactions and is involved in vision, bone development, reproduction and the immunological response.

In practice, feeding levels of 6000 IU for growing-fattening rabbits and 10,000 IU for breeders appear to be sufficient under commercial conditions. The liver can store large quantities of vitamin A.

In contrast to cattle, horses and poultry, rabbits are ‘white fat’ animals and they are not capable of storing carotenoids.

Based on the lack of agreement among authors on the influence of β-carotene on reproduction and the cost of supplementation, caution is needed.

2.2. Vitamin D

Vitamin D is synthesized by the animal when exposed to sunlight. The two major natural sources are cholecalciferol (Vitamin D₃ of animal origin) and ergocalciferol (vitamin D₂ of plan origin).

Vitamin D, after dihydroxylation in the liver and kidney, acts as a hormone and plays a central role in the metabolism of calcium and phosphorus, influencing bone mineralization and mobilization. The classic symptoms of deficiency are rickets in growing animals and osteomalacid in adults.

Excess vitamin D, rather than deficiency is more likely to be problem under practical condition.
The recommended level of vitamin D₃ for rabbits is low and should not exceed 1000-1300 IU.

2.3. Vitamin E

Vitamin E activity is found in a series of eight compounds of plant origin (tocopherols and tocotrienols → d-α tocopherol the most active).

Major functions of vitamin E are synthesis of prostaglandins, blood clotting, and stability of membrane structure and modulation of the immune response.

The main signs of vitamin E deficiency are muscular dystrophy in growing rabbits and poor reproductive performance with increased abortion rate and stillbirths in pregnant does.

The recommendations are 15 and 50 mg vitamin E/kg for fatteners and does, resp. The recommendations might depend on the amount and fatty acid profile of the fat source used. The inclusion of 200 mg vitamin E/kg in diets supplemented with unsaturated sources has been found to reduce oxidative damage of muscle tissues of rabbits.

3. Water-soluble vitamins

3.1. B vitamins

Appreciable amount of water-soluble vitamins are supplied to rabbits through caecotrophy. In fact, caecotrophy meets rabbit requirements for maintenance and average level of production. However, fast-growing fatteners and high-producing does may respond to additional supplementation of B vitamins:

• thiamine (B1)
• riboflavin (B2)
• pyridoxine (B6)
• niacin (B3)

Dietary ingredients used in rabbit diets, such as lucerne meal, wheat middlings, soybean meal, are excellent source of most B vitamins.

Choline is essential for

• building and maintenance of cell structure as a component of phospholipids,
• fat metabolism in the liver, preventing abnormal lipid accumulation,
• formation of acetylcholine, which allows the transformation of nerve impulses,
• donation of labile methyl groups for the formation methionine, betaine and other metabolites.

Choline is synthesized in the liver. Supplementation of 200 mg/kg diet should suffice for most situations.

Folic acid (vitamin B₉) is important for biosynthesis of nucleic acids and for cell division. 0.1 and 1.5 mg/kg are recommended for growing-fattening and does, resp.

Biotin (vitamin H) is involved in many metabolic reactions, including the interconversion of protein to carbohydrate and carbohydrate to fat. It plays a role in maintaining normal blood glucose when carbohydrate intake is low. 0.01 and 0.08 mg/kg are recommended for fatteners and does, resp.

Thiamine (vitamin B₁) is a coenzyme of certain reactions of the citric acid cycle. The classic symptoms of deficiency are neurological disorders, cardiovascular damage and lack of appetite. It is recommended to supplement the diets of fatteners and does with 0.8 and 1.0 mg thiamine/kg, resp.

Riboflavin (vitamin B₂) is required as a coenzyme in many metabolic processes. Most flavoproteins contain vitamin B2 and, therefore, this vitamin is involved to release of food energy and assimilation of nutrients.
Typical symptoms of deficiency involve the eyes, skin and nervous system. Milk is rich in roboflavin. 3 and 5 mg/kg is recommended for fatteners and does, resp.

Niacin is involved in many metabolic reactions such as electron transport, which yields energy to the animal. It plays a role in tissue integrity, especially of skin, gastrointestinal tract and nervous systems. Deficiency is characterized by hair loss, dermatitis, diarrhoea and lack of appetite. In the rabbit, substantial amounts of niacin are synthesized by the hindgut microorganisms.

Pyridoxine (vitamin B₆) plays a role in the krebs cycle and in amino acid, carbohydrate and fatty acid metabolism. Synthesis of niacin from tryptophan, conversion of linoleic to arachidonic acid, formation of advenalin from phenylalenine and tyroseine, incorporation of iron into haemoglobin and antibody formation are some of the reaction in which pyridoxine is involved. Pyridoxine deficiency produces retarded scaly skin, diarrhoea and fatty liver. In the rabbit, pyridoxine deficiency causes inflammation around the eyes and nose, scaly thickening of the skin around the ears, alopecia in the forelegs and skin desquamation. 0.5 and 1.5 mg/kg are recommended for fatteners and does, resp.

Pantothenic acid (vitamin B₅) is a consistent of coenzyme A and acyl carrier proteins, key metabolites in tissue metabolism. Pantothenic acid deficiency reduces growth and produces symptoms such as skin lesions, nervous disorders, gastrointestinal disturbances, impairment of adrenal function and decreased resistance to infection. No deficiency symptoms have ever been described in the rabbit. 10 and 13 mg/kg are recommended for growers and does, resp.

Vitamin B₁₂ is synthesized in the nature only by microorganisms and is not found in feeds of plan origin. Vitamin B₁₂ is metabolically related to choline, methioine and folacin. Symptoms of deficiency include anaemia, loss of appetite, rough skin, diarrhoea and reduced litter size. Rabbits are capable of producing substantial amounts of vitamin B₁₂ trough caecotrophy, provided that cobalt is available. No deficiency symptoms have ever been described when commercial diets are used. 0.010 to 0.012 mg/kg is recommended for growers and does.
Chapter 11. ALTERNATIVES TO ANTIBIOTIC GROWTH PROMOTERS IN RABBIT FEEDING

Amounts of antibiotics were used in animal production, both
• as therapeutic and
• as growth promoting agents.

Therapeutic usage of antibiotics is typically a high dose-short term one, the substance being either injected, or administrated via feed or water.

Growth-promoting usage is typically the opposite, i.e., low dose-long term administration, usually given in feed.

1. Dietary antibiotics in rabbits

Some antibiotic growth promoters improve the performance of rabbits.

Zinc bacitracin was the most used antibiotic growth promoter in rabbit feed.

2. The antibiotic ban

Increasing worries with food safety led European consumers to oppose the usage of antibiotic growth promoters.

Part of the worry with the antibiotic growth promoters had to do with eventual antibiotic residues in meat, milk and eggs.

Growing criticism of antibiotic growth promoter utilization in animal production fuelled the research for non-antibiotic substances, which might have similar effects in food-producing animals.

Among the many alternatives,
• probiotics,
• prebiotics,
• symbiotics,
• enzymes and
• organic acids

were the most studied and developed.

3. Probiotics

Probiotics are live microorganisms which when administered in adequate amounts confer a heath benefit on the host. (Definition by FAO/WHO.)

Several authors have suggested a number of possible mechanisms of action of probiotics, among which a reduction of metabolic reactions which produce toxic substances, the stimulation of host enzymes, the production of vitamins or antimicrobial substances, the competition of adhesion to epithelial cells and increased resistance to colonization, and the stimulation of the immune system of the host.

Most microorganisms used in probiotics are strains of Gram-positive bacteria of the genera
**Bacillus**

* B. cereus, var. toyoi
* B. licheniformis
* B. substilis
* Enterococcus
* E. faecium
* Lactobacillus
* L. acidophilus
* L. casei
* L. farcininis
* L. plantarum
* L. rhamnosus
* Pedicoccus
* P. acidilactici
* Streptococcus
* S. infantarius

Some yeast and fungi are also used, most frequently some strain of Saccharomyces cerevisiae.

At this moment there are two probiotics approved for rabbits in the EU. One of them is bacterial, i.e. *Bacillus cereus var. toyoi*, the other is the yeast, i.e. *Saccharomyces cerevisiae* NCYC Sc 47.

### 4. Prebiotics

Prebiotics are non-digestible food ingredients (oligosaccharides) by the animal enzymes that stimulate the growth and/or activity of bacteria in the digestive system in ways claimed to be beneficial to health.

The main commercial oligosaccharides are nowadays:

- FOS: fructo-oligosaccharides
- GOS: α-galacto-oligosaccharides
- TOS: transgalacto-oligosaccharides
- MOS: mannan-oligosaccharides
- XOS: xilo-oligosaccharides

While probiotics are meant to bring beneficial microbes to the gut, oligosaccharides are supposed to selectively stimulate the beneficial microbes that already live there. They have two clear advantages relative to probiotics:

- a technological one, because there are no critical problems with the thermal proceeding of the feed and the acid conditions of the stomach,
- a safety one, because they do not introduce foreign microbial species into the gut.
5. Prebiotics for rabbits

Some prebiotics effect on the production performance, and/or caecal microbiota and on gut morphology.

In rabbits, prebiotics should create unfavourable conditions for pathogenic microorganisms in the caecum.

Lack of consistency in the results obtained with prebiotics can be explained:

- prebiotics which show benefits in long-living animals, do not show them in short-living species as rabbits
- It should not be forgotten that rabbit diets are naturally rich in fibrous feedstuffs, some of them having significant amounts of oligosaccharides.

6.

Most of the trials that were performed could not detect any significant effect of enzymes on rabbit performances. The only exception was the decrease in mortality with proteases and proteases + xylanases.

In some trials enzymes improved fibre digestion. Improvements were detected when cellulose and enzyme pool were added.

Although rabbits are better able to digest phytic phosphorus than poultry and swine, exogenous phytases improved not only the utilization of phosphorus, but also increased nitrogen digestibility.

Phytases can be useful in rabbit diets.

It is not unlikely that, due to its peculiar digestive physiology, and in particular the fact that caecotrophy casts microbial enzymes along the whole length of the gut, rabbits are less responsive than other animals to supplementation with exogenous enzymes.

7. Organic acids

Most common used organic acids are:

- formic
- acetic
- propionic
- butyric
- lactic
- sorbic
- fumaric
- tartaric
- citric

Studies of organic acids are few, and their results far from consistent.

The inclusion of 1.5% of fumaric acid in the feeds of growing rabbits trended to improve both the daily gain and the feed efficiency, but the differences were not statistically significant.

8. Medium-chain fatty acids
The inclusion of medium-chain fatty acids (0.5% of caprylic acid) reduced post-weaning mortality, without affecting other performance trait.

Although results have often been inconsistent, a number of studies suggest that it will be possible to develop alternatives for rabbits as well.

Combinations of two or more of these types of products, as in symbiotics, are still an opportunity to fully explore.
Chapter 12. THE ROLE OF RABBIT MEAT AS FUNCTIONAL FOOD

Rabbit meat offers excellent nutritive and dietetic properties. Its proximate composition demonstrates its protein richness (about 22% when considering the loin -m. Longissimus dorsi or LD- and hindleg meat). Along with a high protein content, rabbit meat also contains high essential amino-acids levels (EAA). The lean meat portion (water and protein contents) is rather constant (73.0±2.3 g water and 21.5±1.4 g protein/100 g meat). Mineral content is also constant at around 1.2-1.3 g/100 g meat. Lipid content depends greatly on the meat portion considered, but also on different productive factors, especially feeding factors.

Meat and meat products are furthermore major sources for many customary vital nutrients such as zinc and iron (particularly abundant in red meats), selenium (high in beef, chicken and rabbit meats), B vitamins, phosphorous, magnesium, cobalt (all meats are rich in). They could contribute to the intake of vitamin E, minerals such as Ca, Mg, K, as well as omega-3 fatty acids (FA), that are the major nutrients often under consumed by adults.

Meat and meat products are also associated with nutrients that are often considered negative, including high fat and caloric contents, high levels of saturated fatty acids (SFA), cholesterol and sodium, as related to cardiovascular diseases, hypertension, obesity and diabetes. Some of these negative nutrients in meats can be minimized by selection of the meat portion consumed, but also by productive factors’ manipulation, especially feeding factors.

Feeding strategies for the introduction of qualitative and/or quantitative modifications in meat and meat derivatives should concern the ability to limit the concentration of compounds with adverse physiological effects and the enhancement of the concentration of other, beneficial ones.

1. Rabbit feeding and meat quality

1.1. Selenium and Zinc

Selenium is an essential trace mineral for human and animal because it is involved in regulating various physiological functions as an integral part of selenoproteins, some of which (Glutathione peroxidase –GSHPx– and thioredoxin reductase) are part of the body’s antioxidant defense system. The recommended selenium daily intake for adult males and females is 70 and 55 µg/day in the USA and 75 and 60 µg/day in the UK, respectively.

Rabbit meat selenium levels vary widely according to dietary selenium supplementation, ranging from 9.3-15.0 µg/100 g in non-supplemented to about 39.5 µg/100 g with a supplementation of 0.50 mg of selenized yeast/kg feed and to 24-29 µg/100 g with a supplementation of 0.40 mg of selenized yeast or selenized algae/kg feed. The few existing studies in the rabbit didn’t report any effect of the selenium dietary fortification on the meat oxidative stability.

Considered the above indicated recommended daily intake (RDI) of selenium, 140 g of meat from selenium-fortified rabbits would cover the RDI for adults. The results up to now obtained show that selenium-fortified rabbit meat could contribute significantly to the selenium intake of humans, and may be considered a food with functional properties.

As well as selenium, also zinc form part of antioxidant in some animal species; thus, the dietary supplementation with zinc was recently investigated on rabbit meat oxidation and mineral content. 200 mg/kg of zinc did not affect the oxidation (TBARS) of raw and refrigerated cooked rabbit meat, and did not modify the content of zinc, iron or selenium in meat, but it reduced its copper content.

1.2. Vitamins

1.2.1. B12 vitamin and Folate
As vitamin B<sub>12</sub> is found only in foods that come from animals, dietary vitamin B<sub>12</sub> deficiency due to vegetarianism is increasing in developed countries with increased risk of nervous system pathologies and pernicious anemia. One hundred g of rabbit meat provides three times the RDI of vitamin B<sub>12</sub>

Folate is essential for normal cell growth and replication. Folate deficiency can result in many health problems. RDI is 400 µg/d for adults, but folate intake from population, particularly among women, is much lower. Muscle foods contribution is limited but not negligible in a balanced diet, particularly if they are enriched with folate.

Only a few studies have examined the addition of this vitamin to meat products. Fortification of rabbit meat products with folate is also desirable, obtaining a potentially functional fresh product.

### 1.2.2. Antioxidant vitamins

The main problem associated with the increase in the PUFA content in meats is the ability of unsaturated fatty acids (mainly with more than two double bonds) to oxidize and to reduce the shelf-life of meat or meat products. This problem would be more serious when meat is minced, stored for long time or cooked. The formation of oxidation products has been demonstrated to exert an impact on ageing, cancer and cardiovascular disease (CVD). The rate of lipid oxidation can be effectively retarded by the use of antioxidant vitamins, such as vitamins A, C and E. Reminding that these vitamins are consumed at levels below their recommended dietary intake levels by many consumers, they could potentially be used in animal feeding for the dual purpose of cover the human requirements and enhance stability of meat lipids.

Vitamin E is essential for growth, immune function enhancement, tissue integrity, reproduction, disease prevention, and antioxidant function in biological systems. Muscle foods are important source of vitamin E with poultry and rabbit meat being the most important source. Muscle foods could be even better sources of vitamin E through dietary supplementation with α-tocopheryl acetate. However the main interest to fortify meat and meat products with α-tocopheryl acetate is related to its high antioxidant property. As a consequence, vitamin E supplementation extends the shelf life of the meat but also improves its quality characteristics such as colour, flavour, texture.

As for other meats also rabbit meat can be fortified with vitamin E (α-tocopherol) through dietary supplementation of α-tocopheryl acetate. It was found that the vitamin E content in rabbit meat can be increased by over 2 fold with extra dietary supplements of 200 mg α-tocopheryl acetate/kg diet. It improves the nutritional value of the meat.

The natural form of vitamin E (d-α-tocopheryl, a by-product of the oil industry) was more efficient in improving the oxidative stability of rabbit meat compared to the synthetic form (dl-α-tocopheryl acetate). Cooking practice reduced α-tocopherol by in rabbit meat. However, the vitamin E level of cooked meat depends on the cooking method, being the resistance of vitamin E higher for fried and roasted meat than for boiled meat.

The effect of dietary synergistic supplementation of Vitamins E and C have been also investigated, leading to an increase in both the vitamins content and reducing the oxidation of the lipids.

### 1.3. Natural products with antioxidant properties

Some herbs and spices (rosemary, sage, cinnamon, clove, green tea, nutmeg, rose petals) could be efficient food ingredients for improving shelf life of meats (mainly processed) vulnerable to oxidative changes. In fact, they contain many phytochemicals that are potential sources of natural antioxidants, including flavonoids, tannins, phenolic acids, phenolic diterpenes, but they have also anti-inflammatory, antimicrobial and anticancer activities. Other natural antioxidants extracted from plants, such as soybean, citrus peel, sesame seed, olives, carob pod, grape skin, could be used because of their equivalent or greater effect on the inhibition of lipid oxidation.

For all these scientifically proved properties, some herbs and spices can be used to add functional properties to meats and meat products, but they must not exert a negative effect on their physical and sensory properties.

**Oregano** *(Origanum vulgare subsp. hirtum)* essential oil contains phenolic antioxidants. Dietary oregano essential oil exerted a significant antioxidant effect at the level of 200 mg/kg and lowered average microbial counts on the carcasses throughout storage.
**Salvia hispanica**, commonly known as *chia*, is very rich in omega-3 fatty acids, mostly α-linolenic acid. Chia seed oil is also a source of potent antioxidants. In rabbits, unfortunately, the chia seed dietary supplementation at a dose of 15% increased the lipid oxidation of the ground hindleg meat, significantly, due to the increased PUFA level.

In rabbit meat industry the production of processed rabbit meat is not yet so developed and thus scientists lacked interest in evaluating the antioxidant and antimicrobial properties of essential oil and extracts from many plants (oregano, sage, thyme, rosemary, etc.).

Among the natural antioxidants, tannins seem to be potential candidates. Tannins are a heterogeneous group of phenolic polymers and can be divided into hydrolysable tannins and condensed tannins. Altogether, tannins are reported to have various physiological effects like antiphlogistic, antimicrobial and antiparasitic effects. In the rabbit meat, condensed tannins of red quebracho tree have been demonstrated to increase the \( b^* \) value. 0.6% supplementation level significantly increased SFA and MUFA contents whereas meat colour, TBARS value and conjugated dienes were not affected by the tannin supplementation.

**Spirulina platensis** (a blue-green microalga) has recently attracted the attention of scientists due to its potential health benefit, such as antiobesity, lipid lowering, hypcholesterolemic action and antioxidant effect. Spirulina is a rich source of protein (over 60%), β-carotene, α-tocopherol, vitamin B1, and essential FA, mainly γ-linolenic acid (GLA). A reduction in digestibility of quite all nutrients, except for crude protein digestibility was observed. Meat lipid content increased in rabbits fed Spirulina at 5% inclusion onwards and GLA linearly increased with increasing Spirulina inclusion level.

### 1.4. Unsaturated Fatty Acids

Fatty acid (FA) composition has a considerable effect on the diet/health relationship, since each FA affects the plasmatic lipids differently. In general, SFA increase low density lipoprotein (LDL) cholesterol levels in the plasma and thus increases CVD risk, while PUFA decrease LDL cholesterol levels. For this reason there is much interest in increasing PUFA, and especially long chain n-3 PUFA of which many other beneficial effects are well known, into meat and meat products. According to FAO/WHO, the recommended dose of essential PUFA in a healthy diet in daily nutrition is 5:1 (n-6/n-3) but a lower ratio is more desirable in reducing the risk of many of the chronic diseases even though the optimal ratio may vary with the disease under consideration. On the other hand, the absolute intake of long chain n-3 PUFA is much more important than n-6/n-3 ratio.

The FA composition of muscle foods from monogastric animals, such as pigs, poultry, rabbit and fish, can be easily altered by diet, and thus PUFA content could be increased by supplementing diets with vegetable oils, such as linseed and rapeseed oil, or with fish oils. Moreover, PUFA in meats could be increased by dietary supplementation with raw materials such as acorn, or linseed or by grass feeding. It seems that grass feeding has a special ability to raise DHA levels.

As regards fat composition, rabbit meat could be a very useful food in human diets. In rabbit meat, unsaturated fatty acids (UFA) represent around 60% of the total FA, and the PUFA amount, which represents 32.5% of the total FA, is much higher than that found in other meats.

Linoleic acid (18:2n-6) is a major ingredient of feeds for all species, derived entirely from the diet, and its incorporation into adipose tissue and muscle in relation to the amount in the diet is greater than that of other FA. In the rabbit meat, it represents 22% of total FA.

α-linolenic acid (18:3n-3) is the major FA in alfalfa grass, a raw material usually abundant in rabbit feed. As a result, linolenic acid is remarkably abundant also in the rabbit meat, accounting for 3.3% of the total FA. The abundance of α-linolenic acid in the rabbit lean meat contribute to the highest proportion of total n-3 FA (5.5% total FA) among the meats.

Within long chain (C20-22) PUFA the eicosapentaenoic acid (EPA, 20:5n-3) content in rabbit loin meat is found equal to 0.15% and docosahexaenoic acid (DHA, 22:6n-3) content equal to 0.31% of total FA. Comparing the n-6/n-3 ratio of lean meats it emerges that rabbit loin possesses a fairly low ratio (7.0), lower than that of beef (8.9) and pork (21.9) loin, of chicken breast (15.8), and comparable to veal loin meat (6.6).

EPA and DHA are the most bioactive form of n-3 FA whereas α-linolenic acid has very little bioactivity since its conversion to EPA is very low in humans (17:1) (Decker and Park, 2010); these two functional food ingredients have been demonstrated to be easily increased in the rabbit meat trough animal feeding.
The FA profile of the rabbit meat can be easily modified by feeding.

As for other monogastric animals, the increase in n-3 PUFA content of rabbit meat may be performed by supplementing diets with vegetable oil, or with raw materials rich in n-3 PUFA. The substitution of animal fat with vegetable oil sources (soybean, sunflower, rapeseed, coconut, palm, etc.) in rabbit diets was the first approach for increasing the PUFA in meats.

Subsequently, the use of linseed oil (source of linolenic acid) in rabbit feeding was explored as a way to raise the content of n-3 PUFA and to reduce the ratio n-6/n-3 PUFA in meats. All studies evidenced the great ability of rabbit to synthesize long chain PUFA (EPA and DHA) from the dietary precursor, leading to an increase in n-3 PUFA content of the meat and a reduction in n-6/n-3 ratio. However the oxidative stability worsened with linseed oil supplement, which was prevented by dietary supplementation with α-tocopheryl acetate at doses 100 mg/kg.

More recently, various scientists tested the use of linseed as raw material in rabbit feeding. The influence of dietary use of whole linseed (8%) on rabbit meat quality, and found a significant decrease in the n-6/n-3 ratio. Linseed supplementation significantly lowered SFA content and increased PUFA content in meats, but the increase of C18:3 n-3 was the most noticeable. As expected, the n-6/n-3 ratio decreased remarkably.

Nevertheless, the authors consider suitable a 3% linseed dietary supplementation, for achieving both the enrichment of the meat with α-linolenic acid and maintaining good product quality characteristics.

In many studies the linseed supplementation was supplied from weaning up to slaughter, but it was observed that a short term dietary supplementation was effective as well.

Results supported that, in the rabbit, the FA profile of muscles can be effectively modified by two-three weeks of dietary supplementation. The late administration of linseed-enriched diets to fattening rabbits is sufficient to increase the PUFA content in the meat to a requested value, thus reducing the costs in comparison with a longer treatment.

The increase of the PUFA content in meats produced by the dietary use of linseed could lead to oxidation and reduction of the shelf life of the meat α-tocopheryl-acetate.

Other strategies for increasing long chain FA such as EPA, DPA and DHA in rabbit meats are based on the dietary use of fish meal or fish oil. However, some problems related to high lipid oxidation in feeds, impaired rabbit growth, and lower quality and shelf life of the meat have limited the interest towards these ingredients.

Some feeds or by-products, most of local origin and therefore of local use, have been studied in recent years to check their efficacy as rabbit feed, or as sources of n-3 PUFA. The substitution of 48% alfalfa with mulberry leaves impaired food intake and weight gain, and carcasses resulted leaner, whereas hindleg lipids were more rich in PUFA and had a lower n-6/n-3 ratio.

The dietary supplementation with false flax (Camelina sativa L.) seeds or chia seeds increased significantly PUFA content and reduced n-6/n-3 ratio in meats. Chia seeds were very effective in increasing the n-3 PUFA and it could be potentially used to obtain functional meats, only if supplemented with high level of antioxidants, however.

Rabbits contain odd-numbered and branched-chain FA (of microbial origin) in their meat, due to caecotrophy. To some of the branched-chain FA (BCFA) have been recognized the property to inhibit the growth of various cancer cells both in vitro and in vivo.

The high forage diet increased the total BCFA in meat by quite 50%. Rabbits were fed with high digestible fibre (HDF) level (260 g/kg DM) compared to a control diet having 180 g/kg DM. Whereas fatness and SFA were not affected by the dietary treatment, the meat of rabbits fed the HDF diet showed significantly lower MUFA and higher PUFA contents, attributed the latter, to its higher linoleic acid percentage. Interestingly, the HDF diet increased significantly the amount of BCFA in the meat, and thus it can affect the potential nutritive value of the rabbit meat.

In many researches the rabbit meat is evaluated raw, although cooked meat should be examined, as consumers eat rabbit meat always cooked (roasted, fried). On overall, the total lipids and FA content of cooked meat increases, because of the cooking losses. SFA and MUFA contents do not change significantly but PUFA, and
among them C18:2 n-6 and C18:3 n-3 FA, generally decreases after cooking. However, supra-nutritional levels of α-tocopheryl acetate seem to be effective to limit PUFA losses during heating.

1.5. Conjugated linoleic acid

Interests in Conjugated linoleic acid (CLA) have increased in the last two decades for its potential health benefits in humans: anti-cancer property (the natural occurring cis-9, trans-11 CLA isomer), antioxidant, antiatherosclerotic, anti-diabeticogenic, protection of immune system, contribution to bone formation (both cis-9, trans-11 CLA and trans-10, cis-12 CLA isomers), antiobesity property (the 10-trans, 12-cis CLA). Food sources originated from ruminants (milk and dairy products) are known to have markedly higher CLA concentration than those from monogastric animals. CLA is at higher proportions in neutral lipid than phospholipid and higher in adipose tissue than muscle, thus CLA level increases with animal fatness.

Monogastrics are unable to synthesize CLA, therefore the CLA presents in their meat comes from diet.

Recently, CLA is receiving a great deal of attention as a supplement in rabbit feed. However, differently from other monogastrics, the rabbits, by means of caecotrophy, can retain CLA in their meat.

CLA concentration in the rabbit meat may be increased by dietary supplementation of synthetic CLA.

Dietary CLA inclusion has been shown to improve also rabbit body composition due to its potential to reduce fat and favour lean tissue deposition. These studies pointed out that the effect of dietary CLA supplementation depends on the extension and dose of dietary CLA but also on the animal age. Rabbit growth performance and carcass traits at commercial slaughter weight (2.5 kg, 76 d) were not affected by dietary CLA supplementation of 0.25 or 0.50%. However, at heavier slaughter weight (3.1 kg) the highest CLA supplementation level reduced perirenal fat weight, lowered concentration of serum triglycerides and total cholesterol, decreased the meat lipid content and improved its oxidative stability.

On CLA treated groups the content of total SFA increased and that of MUFA decreased, both in loin and hindleg meat, but, this time, PUFA content increased significantly. The concentration of CLA in tissue lipids increased with increasing CLA content in the diet. Duration of CLA feeding had no significant effect on CLA deposition. Thus, dietary inclusion of CLA at higher concentration and feeding CLA-supplemented diet for a shorter period seems to be more suitable for producing CLA-enriched rabbit meat at lower costs.

2. Conclusions

Regular rabbit meat consumption could provide consumers with bioactive compounds, since manipulation of rabbit’s diet is very effective in increasing the levels of PUFA, CLA, EPA, DHA, vitamin E, selenium etc. and lowering n-6/n-3 ratio which play a role over the control of CVD and some other chronic diseases. Although rabbit meat offers excellent nutritional and dietetic properties per se, its dietary fortification with bioactive compounds can be achieved in different ways to obtain meat considered as healthier or functional:

• by feeding rabbits with diets supplemented with high PUFA or long chain n-3 FA content (e.g. linseed – whole or oil and fish oil) the meat is enriched with essential FA and bioactive form of n-3 FA, since the muscle FA profile linearly respond to that of the feed

• a maximum of 4% linseed level in rabbits diet could be considered adequate to achieve both the enrichment of n-3 FA and maintain good product quality

• dietary supplementation with PUFA-rich sources (e.g. linseed) is effective within a range of 2-4 weeks-feeding before slaughter

• in order to improve oxidative stability of rabbit meat, the use of antioxidants is needed. Based on the literature, 200 mg α-tocopheryl acetate/kg feed protect meat from oxidation and extend its shelf life, and provides high levels of vitamin E in meat

• through dietary fortification with 0.5% CLA, the CLA content in rabbit meat represents an opportunity to provide a value-added healthy meat product for human consumption

• supra-nutritional levels of selenium (0.5 mg/kg diet) are able to produce selenium-fortified rabbit meat which could contribute significantly to the selenium intake of humans
• high digestible fibre diets can enrich the rabbit meat with biologically significant branched-chain FA
Chapter 13. NUTRITION AND FEEDING STRATEGY: INTERACTIONS WITH PATHOLOGY

1. Methods to estimate health status and measure the risk of digestive troubles

A common indicator used to evaluate the impact of a disease in breeding is the mortality rate. A morbidity indicator has been developed for the growing rabbit to more precisely assess the indicate of clinical symptoms, and it may be combined with mortality to obtain the health risk index (HRi = morbidity + mortality rate).

2. Problems related to major nutrient imbalances

Among the various health problems related to feeding, intestinal pathology and respiratory diseases are the predominant causes of morbidity and mortality in commercial rabbit husbandry. The first mainly occurs in young rabbits after weaning (4-10 weeks of age), while the second preferentially affects adults.

Enteritis in growing rabbits induced mortality rate of 11-12% before the appearance of epizootic rabbit enteropathy (ERE).

Digestive disorders are responsible for morbidity characterized by growth depression and poor feed conversion. These economic losses are often underestimated by rabbit breeders.

Several factors are involved in the development of enteritis and must be considered:

• status of the animal itself (age, genetics, immunity),
• pathogenic agents (parasites, bacteria, viruses),
• environmental factors, including nutritional factors and breeding conditions such as hygiene, stress and so on.

Although many factors are able to provoke enteritis, the main and constant clinical sign observed in the diarrhoea. This may be related to the characteristics of the rabbit intestinal tract and its complex physiology.

The composition of caecal contents as well as caecal function and caecal bacterial community and activity are significantly affected in cases of enteritis.

3. Fibre and starch requirement

The period just after weaning is critical because it is associated with

• a large incidence of digestive problems,
• overall digestive physiology actively matures,
• feed intake rapidly increases.

4. Effect of the type of cell wall constituents'

One criterion is not sufficient for fibre recommendation, because the risk of digestive problem in the growing rabbit is jointly dependent on the low-digested ADF and the DgF fraction.

The favourable effect of lignocellulose (ADF) on digestive disorders and mortality in fattening rabbits has been established.
The favourable effect of the lignin (ADL) has also been demonstrated, and a strong negative relationship was found with the HRi.

Increasing the cellulose fraction also favours digestive health.

However, lignin plays a specific role since an increase in the ratio of lignin to cellulose is associated with lower HRi.

The level of more digestible fibre (DgF) fractions (i.e. hemicelluloses + water-soluble pectins) could also vary independently of lignin and cellulose level.

Thus, a dietary recommendation for lignocellulose alone appears to be insufficient to prevent digestive disturbances in the rabbit.

5. Protein level

Weaning implies a change from milk to vegetable proteins. The digestion of the later is worse, and raw materials occasionally contain antinutritive factors such lectins, antitrypsin or antigenic compounds.

Most feed manufacturers limit the dietary protein level in fattening diet because of the increased mortality rate on rabbit farm when protein levels exceed by 2% or more the minimum level recommended for the maximum growth rate.

An excessive protein supply increases the dietary cost and nitrogen excretion to the environment.

6. Lipids

It is difficult to separate the effect of lipids from that of the DE intake.

The addition of fat to starter diets increases the energy intake of kits and contributes to the maintenance of good body condition. This favors harmonious digestive maturation and immune system development, thus reducing weaning risk and improving resistance to digestive problems.

It has been found that some medium-chain fatty acids (MCFA), such caprylic and capric acid exhibit antimicrobial activity for some bacteria of caecal digestive microbiota. Moreover maternal milk, rich in MCFA, protects the young rabbits against colibacillosis. The addition of MCFA to the feed has a favorable impact on the digestive health of the growing rabbits.

Some fatty acids, such omega (n)-3, have been implicated in the development of an immune response.

7. Feed intake strategy

The effect of a quantitative linear reduction of feed intake level on the digestive health and growth of rabbit was measured.

During feed restriction, the mortality and morbidity were significantly reduced.

Feed restriction for 3 weeks after weaning reduced the growth rate.

Returning to ad libitum feed intake led to compensatory growth and better feed efficiency.

Over the whole fattening period, the live weight of restricted rabbits was lower with some percent compared to the control group fed ad libitum from weaning.

Similar results have been obtained by reducing the intake level through a time restriction for water consumption.

Consequently, strategies for controlling the intake of the young after weaning are how widespread in professional breeders, in parallel with the development of automatic feeding equipment.

8. Mycotoxins
Mycotoxins are metabolites produced by certain fungi in the field on standing crops or during the harvesting of feedstuffs. Mould growth can also occur on stored grain or other raw materials because of non-hygienic storage condition. These toxic substances may be contained within the spore or secreted into the substrate on which the fungi are growing. Most of these substances have a high degree of animals toxicity. Feeding rabbits on naturally moulded diets is responsible for many problems such as

- decreased feed intake,
- functional alteration of the liver and genital tract,
- changes in blood constituents.

Mycotoxicoses appear in chronic and acute form.

**Aflatoxins** are naturally occurring toxins produced in grains and other feedstuffs both before and after harvest by toxigenic strains of the fungi

- *aspergillus flavus,*
- *aspergillus parasiticus.*

Aflatoxin B1 is of primary concern because it is the most abundant and the most toxic. Rabbits are extremely sensitive to aflatoxin.

Sign of toxicity include

- hepatic lesions,
- anorexia,
- weight loss.

**Zearalenone** (F-2 toxin) is frequently recovered from maize and other grains contaminated by *Fusarium graminearum.*

It causes hypertrophic development of the genital tract of the female rabbits.

Levels of F-2 toxin in feed as low as 1-2 ppm can interfere the normal reproductive activity of rabbits when fed only a few days.

Other group of toxins produced by Fusarium species is the trichothecenes: T-2 toxin and vomitoxin.

**T-2 toxin** is produced by some trains of the fungus *Fusarium tricinctum.* It is relatively common in fibrous raw materials that have been harvested or stored in poor condition. In affected rabbits, T-2 toxin causes

- marked feed refusal,
- lesions of the digestive tract,
- impairment of blood-clotting mechanisms.

Administration per os of 4 mg/kg BW of T-2 toxin causes death within 24h.

**Vomitoxin** may be found in cereal grains. Contamination of rabbit feed with this toxin results in feed refusal and vomiting. Adverse effects on fetal development have also been encountered in does.

The **nephrotoxins** (ochratoxin and citrinin) have been implicated in rabbit mycotoxicosis.

**Ochratoxin** is produced by toxigenic strains of *Aspergillus ochraceus.* The actual toxicity for rabbits is unknown.
Citrinin is found in mouldy cereals contaminated by various fungal species of *Aspergillus* and *Penicillium*. Ingestion of this toxin induces acute erosive gastritis and fluid diarrhea, with some rabbits dying less than 24h after oral administration of a single 100-300 mg/kg BW dose.
Chapter 14. NUTRITION AND FEEDING STRATEGY: FEED FORMULATIONS

Breeding does and their kits are able to

- wean >60 kits,
- produce ten times their body in milk per year,
- the fast growth rate allows multiplication of their birth weight by 40-50 at the age of 60-70 days.

1. Level of fibre

Rabbits are capable of achieving a good growth performance on high-fibre diets as a result of their particular digestive physiology. Maximum growth rates are reached with diet containing about 18-21% ADF, with corresponds to 9.7-10.3 MJ/kg DE.

Experimental results indicated that dietary levels of neutral detergent fibre (NDF), ADF and starch of around 32, 17 and 18%, resp., where optimal for maximal reproductive performance, growth of young rabbits and feed efficiency.

1.1. Type of fibre

Lucerne hay is the most widely used fibre source in rabbit diets, accounting for around 25-40% of commercial pellet. Lucerne hay is highly palatable and provides both long and digestible fibre, which allows an adequate transit time of the digesta and balanced growth of the caecal flora.

Dietary inclusion of fibrous by-products at a level of 10-15% has little effect on rabbit performance.

The inclusion of moderate levels of soluble fibre (12% soluble NDF) in post-weaning diets has been shown to improve the immune response and reduce the deterioration of mucosa after weaning, pathogen proliferation in the gut and fattening mortality.

2. Fat supplementation

Fat inclusion (3%) had a positive effect on energy digestibility (5%) and feed efficiency (7%) but not on growth rate, as feed intake decreased by 6%.

The beneficial effect of fat inclusion were more pronounced for does than for growing rabbits. The inclusion of 3.5% fat in doe diets increased DE intake by 14.5%, which promoted an increase in milk yield and litter weight at weaning by 8.5%. Neither the body weights of does nor fertility or prolificacy were affected by the type of diet, but kit mortality decreased.

Results have shown that diets enriched in n-3 PUFAs decrease mortality during lactation and improve the reproductive efficiency of does.

3. Level and source of protein

It is advisable to express total protein requirement as a ratio between DP and DE. Maximal DE intake and average daily weight gain were obtained for diets with a DP:DE ratio of 10 g DP/MJ DE.

4. Amino acid requirements
Several authors determined the lysine, sulphur and threonine requirements, expressed in digestible instead of crude units.

5. Recommended nutrient concentration diet

The nutrient requirements of intensively reared rabbits are given for the three types of diets more commonly used in practice:

- breeding does,
- fattening rabbits,
- a mixed feed for all animals.

Energy concentrations have been determined from estimates based on the optimal proposed levels of carbohydrates and fat.

Increasing dietary and amino acid content by 10% for the first 2 weeks after weaning are proposed for fattening rabbits.
Chapter 15. FEEDING BEHAVIOUR OF RABBITS

1. Milk intake

Females give birth to naked and blind young in a nest after 31-33 days of gestation. Initial nursing occurs during parturition. Suckling is induced by the mother when she stands motionless over the kits in the nest. She gives no direct association to the offspring to suck.

The nipple-searching behavior is very stereotyped and controlled by a pheromonal signal.

Most of the rabbit suckles their litter for 3-5 min once a day but some does nurse their kits twice a day. If two different females are presented to the litter the young are able to suckle twice a day.

During suckling, competition for access to nipples is very high. Kits do not appropriate a single nipple but change from one to another every 20 seconds within the same suckling bout.

During the first week post-partum, kits drink about 15% of their body weight in milk each day in one nursing session and up to 25% for some individuals. Individual milk intake increases gradually to reach a peak of about 25 g/day.

After day 20-25, maternal milk production progressively decreases. If the female is fertilized just after parturition, and sustains a concurrent pregnancy and lactation, milk production decrease significantly at the end of pregnancy and ceases 2-3 days before the following parturition.

2. Solid feed intake

Young rabbits begin to eat significant quantities of solid food at around 16-18 days of age, when they are able to leave the nest to access a feeder and drinker.

The solid food intake increases from 25 days of age to reach 40-50 g/day by 35 days.

The feeding behaviour changes considerably in a few days, as the young switch from a single daily meal of milk to 25-30 solid and water meals in 24 h.

3. Solid feed intake and evaluation of nutrient and energy supply

In parallel to modifications in feeding behavior, the nutrients ingested by young rabbits change significantly between birth and weaning.

Rabbit milk is very rich in

- lipids (13%),
- proteins (12%),
- contains only traces of lactose.

Pelleted feed mainly contains

- carbohydrates (8%), with varying digestibility ranging from very high for starch to low for fibre.
- protein (15-18%),
- small quantity of lipids (3-5%) all of vegetable origin.
Digestive capacities must evolve rapidly, parallel with the evolution of feeding patterns.

The ingestion of vegetable proteins becomes equal to that from milk at around 25 days of age, and than exceeds it within few days.

Lipids come mainly from milk until weaning.

Ingestion of carbohydrates is virtually zero until 17 days of age, it becomes significant from day 21 in the form of fibre and starch.

4. Regulation of feeding behavior in young rabbits

The availability of milk is a key regulating factor of solid food ingestion before weaning.

Early weaning (before 25 days of age) stimulates and considerably accelerates dry feed intake.

Suckling rabbits regulate their food consumption according to DE content, as do weaned rabbits.

5. Feeding behavior of the growing rabbit

From weaning, the daily feed intake of rabbits increases in relation to metabolic LW, and stabilized at about 5 months of age (140-150 g DM/day).

The intake of soft faeces increases until 2 months of age and then remains steady. Expressed as fresh matter the intake of soft faeces increases from 10 g/day (1 month old) to 35 g/day (2 months), thus representing 15-35% of the feed intake.

6. Feeding behavior of the growing and adult rabbit

The rabbit divides its voluntary solid intake into numerous meals: about 40 at 6 weeks of age, and a slightly lower number in adulthood. The number of liquid meals increases in parallel to that feed and less time is spent drinking than eating. The normal ratio of water to DM is about 1.6-1.8. In the adult or breeding doe it is increased up to 2.0-2.1.

The solid feed is consumed in the dark period for rabbit submitted to a 12-h light, 12-h dark schedule.

The circadian changes in liquid meals are strictly parallel to those of solid meals for rabbit fed pellets.

With older rabbits, the nocturnal feeding behavior becomes more pronounced.

7. Feeding behaviour of the adult rabbit

The feed intake level is modulated by the physiological status of doe. The voluntary intake of does varies during the reproductive cycle, with intake falling markedly during the final days of pregnancy. Some does refuse solid food just before kindling. Water intake, however, never stops completely. After kindling, feed intake increases very rapidly and can exceed 100 g DM/kg LW/day. Water intake is also increased at that time, from 200 to 250 g/kg LW.

8. Feeding composition and presentation form

The rabbit (feed a pelleted balanced diet) is able to regulate its DE intake when the dietary DE concentration is between 9 and 11.5 MJ/kg, or when the dietary fibre level is between 10% and 25% DF. The intake level is thus well correlated with the dietary fibre level, compared to the dietary DE content.

9. Environmental factors affecting the feeding behaviour of the rabbit
9.1. Temperature

Studies on growing rabbits have shown that the intake of pelleted feed drops from 180 to 120 g/day and water intake rises from 330 to 390 g/day at temperature between 5°C and 30°C.

The number of solid meals eaten in 24h drops as temperature increases, from 37 solid feeds at 10°C to 27 feeds at 30°C.

The amount eaten at each meal also decreases with higher temperature (from 5.7 g per meal at 10-20°C to 4.4 g per meal at 30°C).

The negative effect of hot ambient temperature on daily feed intake may be partly counterbalanced by distribution of cooler drinking water (16-20°C). With could water distribution, the average feed intake may be increased by 4-6%.

10. Hunger and thirst

If drinking water is not provided and the only feed available is dry (moisture content of 14%), DM intake drops to zero within 24h. With no water at all an adult rabbit can survival from 4 to 8 days. Rabbits with access to drinking water but no solid feed can survive for 3-4 weeks.

Any reduction in the water supply causes a proportional reduction in DM intake, with a consequent drop on most performance criteria.

Limiting water availability for breeding does to 20 min/day decreases their feed intake, milk production and growth of kits by about 17-18%, but has no effect on reproduction parameters and kit mortality.

11. Environmental factors

11.1. Lighting schedule

In the absence of light (24-h dark) the feed intake of fattening rabbits is increased. Rabbits organize their feeding pattern in a regular 23.3- to 23.8-h programme, with about 5-6h devoted to soft faeces ingestion and the remaining part of the cycle to feed intake.

Under continuous lighting, the feeding pattern is organized in approx. 25-h programme.

11.2. Stocking density

An increase in stocking density seems to lead to reduced feed intake.

11.3. Group size

In comparison of cage and pen housing, enlarging the cage size for a group allows rabbits to move more and reduces daily feed intake.

11.4. Size of feeder

The number of places at a feeder (one to six) for a group of ten rabbits did not influence daily feed intake.

12. Free choice of rabbits

When a choice is proposed between a control diet and the same diet plus as appetiser, rabbits generally prefer the latter.

Rabbit prefer lucerne with a saponin (a bitter component) content of up to 3 mg/g diet.

When a toxin is present (e.g. aflatoxin) rabbits completely refuse to consume the diet or consume it in very low quantities. This regulation may be relevant in protecting the animal against food-borne pathologies.
When a concentrate (low-fibre compound diet) and a fibrous material are offered as free choice to rabbits, they prefer the former.

Receiving a diet deficient in one essential amino acid (lysine or sulphur amino acids) and drinking water with or without the missing amino acid in solution clearly prefer the solution with the missing amino acid.

13. Feed restriction

13.1. Quantitative limitation

For rabbits a quantity representing 85% of the ad libitum of 16 h; if the quantity is reduced to 70%, the time taken to ingest this quantity is reduced to 10 h.

When restricted-fed rabbits are caged in groups, the time spent on feed intake is shorter.

13.2. Restricted access to the feeder

Feed restriction to 8 h/day was associated with a reduction in feed intake of 80% of *ad libitum*. Reducing access time to feeders induces a greater reduction in the intake of young rabbits than in older fattening rabbits.

The total number of meals per day is not affected by time limitation (30-35/day at 12 weeks) but the meals are concentrated in the smaller number of hours available, without a significant increase in the duration of each meal.

14. Restricted access to drinking water

Limitation of the access time to drinkers is another method by which to reduce feed intake.

After a week of adaptation, rabbits receiving free access to drinking water for only 10 min/day reduced their feed intake to 76-86% of that of rabbits drinking *ad libitum*.

The adaptation period was introduced because of the drastic reductions in water and feed intake (-63% and -53%, resp.) in the 1-2 days following the institution of the restriction.

In practical conditions with fattening rabbits, limiting access to drinking water to 1.5-4 h induces a reduction in water intake that is proportionally greater than the concomitant reduction in pelleted feed intake.

With restricted access to drinkers, the water to feed ratio is always reduced.

When feed intake is reduced, the water intake is clearly enhance above the *ad libitum* intake, and the water to feed ratio is increased above that of the control.
Chapter 16. FEEDING SYSTEMS FOR INTENSIVE PRODUCTION

In intensive production systems, rabbits are almost exclusively fed with a balanced compound diet in order to fulfill their dietary requirements, with a view to optimizing their production records and feeding management.

In rabbit meat production feeding costs represent the largest part of the production costs, they amount to 60-70% of the total costs.

1. Effect of diet presentation

Significantly lower amounts of feed are consumed on meal diets, resulting in lower daily weight gain, inferior feed conversion ratio and lower slaughter yield.

2. Pellet size and quality

The length of pellets is preferentially between 8 and 10 mm. Losses of parts of pellets by the rabbits are more frequent at sizes >10 mm.

The preferential pellet diameter is in range of 3-4 mm. At diameters >5 mm, the risk of pellet wastage increases.

Pellet durability and hardness are the major quantity characteristics of rabbit pellets, to avoid excessive fines being produces during handling or transport, especially when using automatic feeders.

3. Feed storage

With the increasing size of rabbit farms, feeds are mainly delivered in bulk.

Packing in bags is still used for small farms or for special feeds (e.g. weaning diets).

Storage time should be limited to 3-4 weeks, employing outdoor silos.

4. Number of diets

In practice, two or three silos (diets) are economically optimum for a middle-sized rabbitry.

About 40-50% of the feed is consumed in the reproduction unit and 50-60% in the fattening unit.

5. Feed intake - growing rabbits

Feed intake increases with age, but not when expressed as kg body weight. The highest feed intake per unit of weight is reached before the maximal growth rate occurs.

6. Practical feeding - young parent stock

*Ad libitum* feeding together with early mating (75-80% of the adult weight) leads to favorable results.

In practice it is recommended to restrict feeding in young does and postpone the first mating until the age of at least 17 weeks, with a target of 85-90% of the adult weight.

Another method to restrict feeding in young parent stock is to use a low-energy (<8 MJ DE/kg), high-fibre diet.

7. Practical feeding - males

Males increase their voluntary feed intake until the age of 5 months.
Excessive feed restriction in males is not recommended. However, males from heavy lines frequently show sore hocks in wire mesh cages; feed restriction reduces their adult weight by about 0.5 kg and consequently favorable effects on longevity may be expected.

8. Practical feeding – lactating does

Lactating females have a high nutrient and energy demand due to their concentrated milk production. A concentrated high-energy lactation diet stimulus daily nutrient and energy intake, and reduces the energy deficit at the end of the lactation.

9. Practical feeding – weaned rabbits

If a specific weaning diet is fed from the age of 3 weeks, this may be continued after weaning until the age of 7-8 weeks.

Once the critical period is passed, rabbits are fed a more concentrated fattening diet.

A phase-feeding programme during the fattening period is designed to reduce mortality, increase biological performance and minimize mineral excretion in order to protect the environment.

A reduction of feed intake by at least 25% has proven to be very helpful in overcoming enteritis problems between the ages of 5 and 8 weeks.

An indirect method of restricting feed intake is to restrict water intake. When the water distribution is limited to 2-3 h/day, feed intake is only 70% of the ad libitum intake. Positive results have been obtained in reducing enteritis and losses due to diarrhea. However, restricting water cannot be defended from a welfare viewpoint and direct feed restriction should be applied to prevent enteritis in young rabbits.

10. Feed conversion ratio (FCR)

The global FCR is defined for a closed unit (maternity and fattening) as the ratio between the kg feed consumed (bought) per kg of rabbits produced (sold).

In the global (farm) feed conversion ratio, reproduction efficiency and slaughter weight are the main factors that influence the FCR.

11. Feed conversion ratio – diet concentration

A rabbit regulates its feed intake according to energy requirement.

12. Feed conversion ratio – mortality

It is evident that mortality has a very large impact on FCR. If mortality occurs in the early fattening stage, the FCR deteriorates only slightly. If the losses are concentrated at the end of fattening period the FCR is worse.
Chapter 17. NUTRITION AND THE CLIMATIC ENVIRONMENT

Biometeorology is the study of the relationship between the environment and living organisms.

In homoeothermic animals, the goal is to maintain a stable body core temperature under most conditions.

1. Environment

Ambient temperature and humidity are the variables that most affect nutrition. Both directly influence the energy equilibrium of the animal, changing the flow of heat between the animal and the environment.

2. Definition of thermal neutrality

The range of ambient temperature as an expression of thermal environment within which metabolic rate are at minimum and temperature regulation is achieved by non-evaporative physical process alone.

3. Posture

Rabbits take on a ball posture at <10°C to decrease their surface area for conduction or radiation loss.

The spread posture at 30°C allows more sensible heat to be dissipated.

4. Hot environment

The ears are a means of dissipating heat. Their heat exchange coefficient about four times the coefficient for the whole animal.

In a wind of 60 m/s, fully dilated ears can lose twice as much heat as ears in non-forced convection.

Most rabbits die after a few days’ exposure to 40°C.

5. Heat stress

Exposure to high ambient temperatures induces rabbits to try to balance the excessive heat load by using different heat dissipation pathways. If such means are not sufficient then physiological traits deteriorate, including depression in feed intake, efficiency and utilization, disturbances in water, protein, energy and mineral metabolism balances, enzymatic reactions, hormonal secretions and blood metabolites.

Thermal stress directly affects reproduction, health and nutrition, and all of these interact with each other. The overall result for animals exposed to thermal stress is always a reduction in productivity, which varies according to the severity of the stress and the acclimatization of the animal.

Depressed feed intake and increased water consumption are the most important reactions to heat expose.

At 30°C rabbits consume only 60-70% of the feed intake recorded at 20°C. In contrast, water requirement increase by 50% as the temperature rises from 18°C to 28°C.

Blood metabolites such as glucose, serum total protein, serum total lipid and cholesterol decrease, which may be correlated to the decrease in energy metabolism during heat exposure.

6. Nutritional value of feedstuffs

In tropical countries, the nutritive value of forages is relatively low, with high indigestible fibre.
Forage alone cannot support high performance in either growth or lactation. Supplementation of pelleted diets with potential energy sources, including roots, tubes, fruits and grain by-products, has generally demonstrated that 50-70% of pellets can be replaced by green forages, by-products or roots without a significant reduction in growth performance.

7. Nutrient allowances and environment

The adverse effect of temperature on efficiency and production should be minimized by adjusting nutrient levels. Assuming that maintenance needs for protein are not influenced by thermal stress, the protein/energy ratio is increased during both cold and heat stress, resulting in excess protein being used as an energy source. The practical approach in cold conditions is to increase dietary energy levels.

The consequences of hot environments on feed intake, which means less protein being ingested and reduced growth, have generally resulted in recommending higher levels of protein in warm climates. The addition of some amino acids, particularly lysine, has alleviated the effect of heat.

High-energy diets have been reported to overcome the lower energy intake in hot environments.

Increased voluntary intake in cold conditions trends to overcome any marginal deficiency in nutrients, although not in energy.

A smaller proportion of dietary protein is needed, and more protein is utilized as an additional energy source.

A high-fat diet has been shown to be most effective means of maintaining body temperature.

The addition of probiotics in hot climates and/or adding disodium or dipotassium carbonate has proved to be effective at high temperature.

The water to food intake ratio of about 2 has been recorded for adult rabbits fed ad libitum at 20°C. There is a rise in the ratio of water intake to DM intake up to 2.4 between 20°C and 30°C.

Drinking cool water has sometimes been recommended in hot situations.

8. Effect of heat stress on breeding does

High ambient temperature appears to act on reproduction both directly and through the depression of voluntary feed intake. Does kept at 35°C die within 72h.

One action would seem to increase the DE of diets with more cereals or by adding fat. Although under normal conditions does compensate for different diet density through corresponding changes in feed intake. Some added fat elicits a better response from does, perhaps related to high milk-fat output.

Low-energy diets gave a poorer response at 30°C constant temperature, while no statistical difference was found between the high-energy diets.

9. Effect of heat stress on males

High ambient temperatures have adverse effects in bucks, potentially producing temporary sterility, decreasing libido, delaying age at first mating and reducing semen quantity and quality.

The effects of heat stress may be due to a decrease in testosterone concentration and spermatogenesis and become more pronounced when relative humidity is high.

High-energy diet alleviates the negative effects of high temperature.

Zinc supplementation has been found to reduce the depression of semen production.

10. Effect of heat stress on growing rabbits
Voluntary feed intake varies according to whether conditions are cold or warm. A reduction in intake occurs at 22-25°C, and certainly impaired growth is assured around 30°C.

A reduction of 25% in feed intake, comparable with the percentage observed in hot climates, should be balanced by about the same increment of dietary nutrients. Both increasing DE by some 10% and increasing protein and lysine, found no improvement in average daily weight gain in rabbits kept at 30°C.

When comparing low- and high-fat diets, while gains at moderate temperatures of 12°C and 18°C were similar, at 24°C, 30°C and 33°C the use of high-fat diets slightly improved growth performance.

Slower growth leads to lighter and leaner carcasses, so that any diet should produce less carcass fat at higher ambient temperature.