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RABBIT NUTRITION AND FEEDING: A REVIEW OF SOME RECENT DEVELOPMENTS

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ABSTRACT : The review examines feed intake regulation, sources of raw materials for rabbit diet formulation, energy evaluation systems, feed additives in rabbit feeding, dietary nutrient recommendations and practical rabbit feeding.

Introduction

In the last decade rabbit meat production has become a real agribusiness in some countries. Especially in some West European countries rabbit production systems have changed a lot, e.g. Italy, France, Spain and to a lower extent Belgium, The Netherlands and Germany. Also in many other parts of the world an interest in or an increase of this production is significant, e.g. Hungary, Egypt, Nigeria, China ...

Although in many areas small scale rabbit production has considerable potential, this paper will emphasize on the nutrition of large scale production. With the increasing size of the rabbit enterprises, feeding and nutrition of rabbits under both production systems become more and more divergent. Units with more than 1,000 does (doe-cages) are common in some countries. They use more and more strict reproduction planning with a weekly, bi-weekly or monthly cycled reproduction. Intensification and rationalisation of rabbit production is further pursued by the increasing use of a highly productive selected reproduction stock (hybrids), an adjusted reproduction system (artificial insemination) and a secure species adapted renewal of breeding stock (day-old rabbits).

Consequences of this development on the feeding and nutrition of different categories of intensively reared rabbits are multiple. Nutrient requirements and dietary recommendations must be related to the increased performance level and prescribe the amount of each essential nutrient that will result in maximum production. Because feed is the largest single item in the cost of producing rabbit meat representing at least 65%, more and more concern is given to minimizing feed costs in large production units. For this goal a good balance between nutrients and a correct evaluation of the raw materials are extremely important to formulate least cost diets. Delivery of bulky feeds and the use of automatic or semi-automatic feeding systems have further practical consequences.

Commercial rabbit production is still characterised by high losses of weanling rabbits. The major part of the average mortality rate of about 10% is ascribed to diarrhea (Peeters, 1988). Because enteric diseases are considered to be closely linked with diet and feeding practices, nutrition-disease interrelationships are an important item in rabbit nutrition and research.

Despite the increasing interest in commercial rabbit production, it remains a minor production compared to cattle, pig or poultry industry. As a consequence research resources for rabbit production are limited, widely scattered and often non-continuous. Research results are to a large extent only published locally; this means in a large variety of languages. In this context, a review concerning the present knowledge about rabbit nutrition runs the risk of being incomplete.

At the 4 former World Rabbit Congresses, comprehensive reviews were presented by outstanding scientists. An excellent and very well documented book by Cheeke was published in 1987. This monograph on rabbit feeding and nutrition is widely used as standard information. Since then various reviews have been published (Santoma et al., 1989; Ruffini Castrovilli & Greppi,1990; Maertens & De Groote, 1991; ...) and especially the regularly updated ones of Lebas (1980,..., 1988, 1989, 1990) are generally recognized.

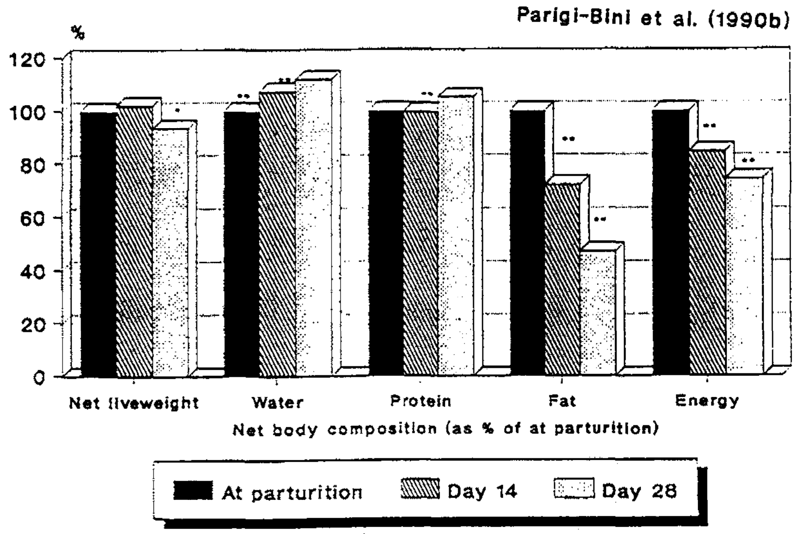
This present paper does not intend to be a duplicate of the fore-mentioned reviews but to emphasize on some aspects of rabbit feeding and nutrition where significant efforts or progress have been made since the Budapest Congress.

1. NUTRIENT REQUIREMENTS

1.1 Reproduction stock

The number of recent long term experiments with does is limited to a few studies (Fraga et al., 1989a & b; Castellini & Battaglini, 1991; Barge et al., 1991). However, with increasing performance level and intensification of the reproduction, the problems of maintaining the does in optimal condition become evident. In this respect, recent work done by Parigi-Bini and collaborators (1990...1991) is of considerable interest to formulate energy and protein requirements in different physiological states.

Fig. 1. EFFECT OF THE LACTATION ON NET BODY COMPOSITION OF PRIMIPAROUS DOES



Studies of the nitrogen balance during pregnancy, lactation or concurrent pregnancy and lactation have clearly shown that the protein status is adequate when providing a balanced protein/energy ratio (Partridge & Allan, 1983; Partridge et al., 1983; Maertens & De Groote, 1988a; Parigi-Bini et al., 1990a; Barge et al., 1991). Nevertheless, protein demand was increased by overlapping pregnancy and lactation due to the high protein content of foetal tissues and the low efficiency (Parigi-Bini et al., 1991b). However, protein requirement does not seem to be the first limiting dietary factor to obtain satisfactory performance if the digestibility of the dietary protein is high. A ratio around 12 g dig. protein/MJ DE is adequate for breeding does. Depending on the breeding program a somewhat higher or lower P/E ratio is claimed for post-partum or semi-intensive breeding (see review Lebas, 1989).

On the other hand, **energy balance** experiments have clearly shown the energy deficiency during the lactation period of highly productive does (Partridge et al., 1983; Partridge et al., 1986a; Partridge et al., 1986b; Parigi-Bini et al., 1990b). As a consequence does lose weight and mobilize body tissue (Fig.1). If the quantity and the quality of the diet do not control this situation, breeding performances may be seriously impaired. For this reason the energy requirements will be treated more in detail.

The requirement of a doe is the sum of maintenance + lactation + pregnancy + possible growth for young does.

The estimate of the digestible energy requirement for maintenance (DEm) depends on the methodology used (respiratory chambers vs comparative slaughters), the physiological state of the doe (Parigi-Bini et al., 1991a) and varies between experiments. In their comparative slaughter experiments with primiparous does, Parigi-Bini et al. (1991) determined a daily DEm of 398 and 431 KJ/kg metabolic weight ($kg^{0.75}$), for non-pregnant and pregnant does respectively. During lactation and lactation + pregnancy, the DEm increased till 432 and 468 KJ/$kg^{0.75}$. Taking also into account the previous estimates (Partridge et al., 1983; Partridge et al., 1986a; Fraga et al., 1989a) the following reference values will be used in order to calculate the overall energy requirements: 420 and 460 KJ DE/$kg^{0.75}$/day for pregnant does and lactating does, respectively.

The requirements for pregnancy depend on the period of pregnancy; on the development of the foetus and placenta. During the first 21 days does can fulfil this requirement with the feed energy (Kamphues, 1985; Partridge et al., 1986a; Parigi-Bini et al., 1990a and 1991) but from then on requirements increase very rapidly while feed intake capacity is dropping (Kamphues, 1985; Partridge et al., 1986b; Hullar et al., 1990). During this last week a transfer of energy from the doe's body to the foetuses occurs (Partridge et al., 1986b; Parigi-Bini et al., 1990b). Therefore it is necessary for the doe to build up an energy reserve (weight gain) in early gestation. According to Kamphues (1985) this daily requirement during early pregnancy is estimated as 140 KJ DE/$kg^{0.75}$. During the last week requirements are estimated somewhat higher than twice the maintenance requirement (Kamphues, 1985). But because they may lose some weight, the estimate of 2x maintenance requirement will be used (Table 1).

Lactation requirements are depending on milk yield, milk composition and on the efficiency of dietary DE for milk output. The energy content depends on the stage of lactation (Partridge et al., 1983; Partridge et al., 1986a), being more concentrated with declining milk production. During the first 3 weeks of lactation an average value of around 8 MJ/kg milk was determined (Partridge et al., 1983; Partridge et al., 1986a; Fraga et al., 1989b; Parigi-Bini et al., 1990b). Depending on the pregnancy state of the doe, the energy content increases to about 10 MJ (Partridge et al., 1983; Partridge et al., 1986a; Parigi-Bini et al., 1990b) for non PP pregnant does and to 14.5 MJ for PP pregnant does (Partridge et al, 1986a) at the end of the 4th lactation week. On conventional diets the efficiency of dietary energy utilisation for milk production has been estimated as 63 - 69% (Partridge et al., 1986b; Parigi-Bini et al., 1990b and 1991a).

Milk production is first of all dependent on the lactation day, the number of suckling kits (Lebas, 1987), the physiological state of the doe (concurrent pregnancy or not) and diet (Maertens & De Groote, 1988b) or feed intake level (Parigi-Bini et al., 1991b). Other important effects are breed, parity and of course individual doe differences (McNitt & Lukefahr, 1990). In order to calculate total energy requirements for highly productive does at different physiological states (Table 1), average milk yield data determined in our experimental unit are used (Maertens & De Groote, 1987 & 1988b).

Table 1. Calculated energy requirements of highly productive does at various phases of the reproduction cycle (MJ DE/day for a standard doe of 4 kg)

		Maintenance	Pregnancy	Lactation	Total	Feed[1](g)
Young doe, pregnant (3.2 kg)		1.00	0.55[2]	-	1.55	148
Pregnant doe,	0 - 23 d	1.19	0.40	-	1.59	151
	23- 31 d	1.19	1.19	-	2.38	227
Lactating doe,	day 10	1.30	-	2.89[3,4]	4.19	399
	day 17	1.30	-	3.57	4.87	464
	day 25	1.30	-	3.60	4.90	467
Lact. + PP pregn.,	day 10	1.30	0.40	2.89	4.59	437
	day 17	1.30	0.40	3.57	5.27	502
	day 25	1.30	1.30	1.48	4.08	388
Lact. + 12d PP preg.,	d 10	1.30	-	2.89	4.19	399
	d 17	1.30	0.40	3.57	5.27	502
	d 25	1.30	0.40	3.60	5.30	505
	d 32	1.19	0.40	-	1.59	151

[1]assuming a dietary energy content of 10.5 MJ DE/kg [2]pregnancy + growth

[2]milk yield: d 10: 235g d 17: 290g d 25: 80g (PP pregnant); 260g (non-PP pregnant)

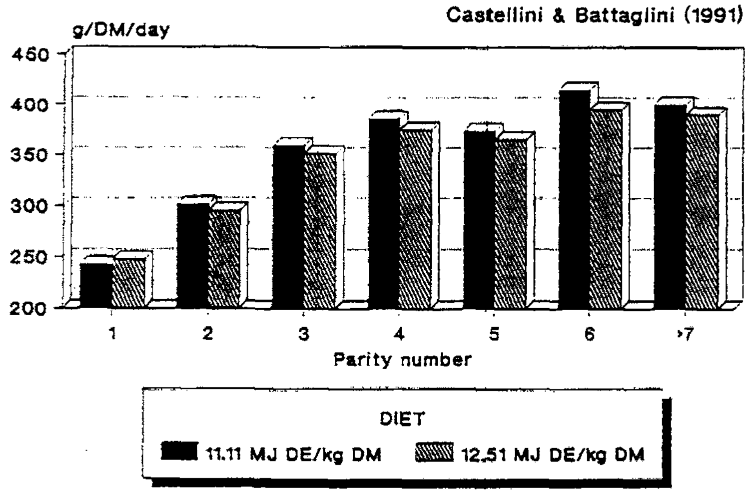
[3]energy content of milk: 8 MJ/kg, except from day 25 on: 9 MJ (non-PP pregnant) and 12 MJ/kg (PP pregnant)

Based on their experimental data and using multiple regression analysis, Fraga et al., (1989a) determined an energetic cost of 11.3 KJ/g milk yield. Compared to the above calculated lactation requirements, the energetic cost is about 8% lower. However, the energy requirements given in Table 1 are calculated to have does in energy equilibrium. In reality does mobilize body tissue and lose body energy. The total loss of energy during the lactation corresponds to 28% of the initial body content in primiparous does (Parigi-Bini et al., 1991a). The efficiency of DE for milk production is estimated at 0.76 - 0.81, depending on the pregnancy status of the doe. However, the requirements as given in Table 1 are in agreement with the determined DE intakes of highly productive does when using diets with high energy density (Maertens & De Groote, 1988a & b; Castellini & Battaglini, 1991).

Partly based on Table 1 some recommendations can be given or problems explained. Young pregnant does or not lactating does can easily fulfil their energy requirements. A feed restriction is necessary in early gestation, to prevent them from extreme fattening. This leads both to high perinatal mortality and to suppression of voluntary feed intake in early lactation (Partridge et al., 1986b). For these does a lower concentrated diet is preferable.

In early lactation does gradually increase their feed consumption (Maertens & De Groote, 1988a; Fraga et al., 1989b), they are still in a positive energy balance and gain weight (Partridge et al., 1983; Parigi-Bini et al., 1990b). However, once milk production becomes important they mobilise more and more body energy for milk production and lose weight (Partridge et al., 1986a; Parigi-Bini et al, 1990b). This is not surprising because at top lactation their total daily energy requirement is about 4.9 MJ or $1.74/kg^{-0.75}$. Expressed in terms of feed intake, this means a daily feed intake of 465 g ($166/kg^{0.75}$) of a concentrated diet or more than 500 g of a less concentrated diet. This quantity is not attainable when a less concentrated diet is fed (Maertens & De Groote, 1988b). Therefore they risk to lose too much weight or become too thin, especially primiparous does (Parigi-Bini et al., 1990b). If they have no period of rest, their bad condition can impair their further reproductive capacities. Multiparous does have a larger intake capacity (Fig. 2) and they will increase their feed intake during the successive litters (Castellini & Battaglini, 1991).

Fig. 2. EFFECT OF PARITY NUMBER AND DIET ON DAILY FEED INTAKE OF DOES (DOE-CAGE)



For both intensive and semi-intensive breeding does, requirements are high. But the PP pregnant doe is channeling nutrients into the next litter in the uterus, rather than into milk (Partridge et al., 1986a; Parigi-Bini et al., 1991a). The energy retained in the foetuses appears to have a high energy cost in lactating and concurrently pregnant does or a low efficiency of 0.27 (Parigi-Bini et al., 1991a). This process is aggravated because feed intake capacity is dropping during the 4th week of pregnancy. To sustain such a situation, besides the energy restore in early lactation, a good balance between the different requirements is necessary. For these does, weaning is necessary at least at day 28 to stop possible further energy output in the milk. For the semi-intensive bred doe, a resting period of 10 or more days is available before the next lactation. If this period is more than 3 weeks, restricted feeding is required.

Especially when an intensive breeding rhythm is used, the need of a concentrated lactation diet has been stressed. In long term experiments significantly higher performances were obtained in favour of high energy feeds (Maertens & De Groote, 1988b; Castellini & Battaglini; 1991). Differences were most pronounced for primiparous does and true PP breeding does. Not all experiments give a clear response to an increased dietary energy content. This can partly be explained by the production level. For example, doe performances (litter weights) were on average 30% lower in a Spanish study (Mendez et al., 1986) in comparison with the above cited experiments (Maertens & De Groote, 1988b; Battaglini & Castellini, 1991). It also has to be stressed, as for other species, that a lot of individual or strain differences exist in intake capacity between does. This is also the case for the way in which they partition nutrients for milk or body size (Partridge et al., 1983). Selection programs have to take this facts into consideration.

To obtain a high energy diet, fat containing feedstuffs such as soybeans or added fat can be used to a certain extent. It has been reported that the digestibility of diets increased (Santoma et al., 1987; Fraga et al., 1989b) or the feed energetic efficiency increased (Partridge et al., 1986b) with added oil or fat. Inclusion of 3.5 % pork lard increased feed intake and consequently DE-intake with beneficial effects on doe and kit performances (Fraga et al., 1989b). The data of Van Maanen et al. (1989) suggest further that isoenergetic amounts of corn oil are utilized more efficiently than carbohydrates.

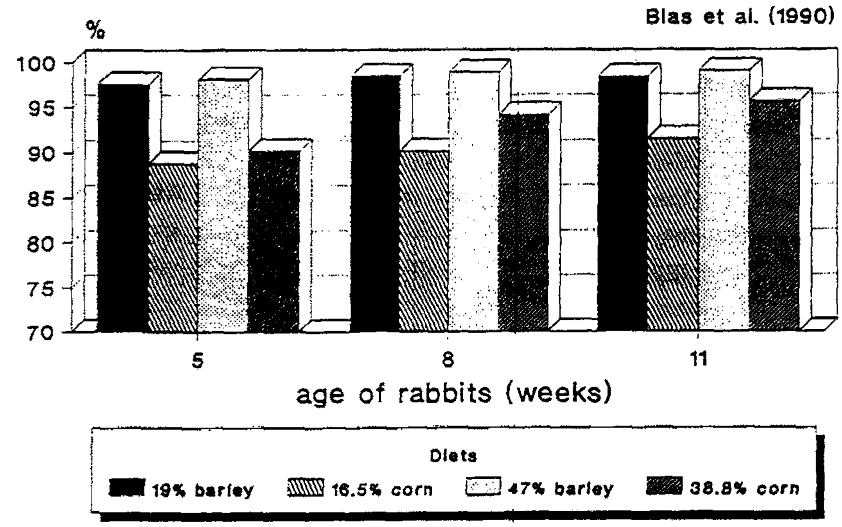
Finally in this chapter, I'd like to emphasize a report concerning the dietary phosphorus level (Lebas & Jouglar, 1990). Especially because in some countries (The Netherlands, Belgium, Germany) efforts are done to reduce the output of minerals through excreta, in order to protect the environnement. Farmers even have to pay per kg of N or P they produce. In this context minimal dietary recommendations are of large importance. In a 6 months experimental period, total phosphorus levels in a range of 0.45% - 0.76% did not affect any of the doe's reproduction performances. The performances of the progeny were independent of their mother's diet. Recently the lack of response to low dietary P-levels has been confirmed with fatteners (Steenland, 1991). Based on these results lower dietary levels of phosphorus may be used than those recommended by Lebas (1989). The ratio Ca/P does not seem to be critical for rabbits (Cheeke, 1987) and is usually 2:1.

1.2. Weanlings

In recent years more information is becoming available concerning the nutrient requirements of kits around weaning. This period, as in other animal species, is critical because of the coincidence of the change from milk to an exclusive intake of solid feed with a greater sensitivity to microbial infections. Intensification of rabbit production has further enhanced the digestive disorders since early weaning is required.

The dietary factor which has recently been related to be a predisposing factor to weaning diarrhea is the starch content. It has been confirmed that young kits have an immature pancreatic enzyme system, which led to significant amounts of starch reaching the cecum when using high starch diets (Blas et al., 1990). However, the ileal starch digestibility of young rabbits is not only age dependent but also dependent of the dietary level and the starch source (Blas et al., 1990; Gidenne et al., 1990a). In this way the starch digestibility of corn based diets was significantly lower compared to barley based diets, especially in early fattening period (Fig. 3). The hypothesis of a starch overload in the hindgut (Cheeke & Patton, 1980) is supported by these results, but only in the period between 21 and 40 days of age, because already in the 5th week of live pancreatic enzyme system shows a rapid development (Corring et al.,1972; Blas, 1986). In older rabbits, the amount of starch which reaches the hindgut is small, even when diets contain a high proportion of cereal grains (Blas, 1986; De Blas et al., 1992); which explains why neither cecal pH nor ammonia concentrations were affected by starch intake (Morisse et al., 1985; De Blas et al., 1986: Carabano et al., 1988).

Fig. 3. STARCH DIGESTIBILITY AS AFFECTED BY STARCH LEVEL & SOURCE AND AGE OF RABBITS



The presence of cecal starch or glucose, which would arise from the starch reaching the hindgut, provides an environment in which pathogens may proliferate; e.g. enterotoxemia caused by *C. spiroforme* (Borriello & Carman, 1983). This relationship between the dietary content and early post-weaning digestive disorders has been confirmed under practical circumstances (Robinson et al., 1988; Lebas & Maitre, 1989). Mortality significantly ($p < 0.05$) increased when using a high starch (± 25%) weaning diet (Table 2).

Table 2. Effect of weaning diet on the early post-weaning mortality
(Lebas et Maitre, 1989)

Diet	A	B
Composition (%/kg)		
Crude protein	15.5	12.9
Crude fiber	14.9	13.6
Starch (±)	15.0	25.0
DE (calculated)	2270	2460
Mortality (%)		
Experiment 1 (n=±300/diet)	2.7	6.9
Experiment 2 (n=±550/diet)	4.9	12.0

Based on these observations it is necessary to put a starch constrain in feed formulation. A low starch level, with respect to optimal protein/energy ratio implies an increased content of cell-wall constituents (De Blas et al., 1981).

Many experiments have shown the favourable effect on mortality of a high content of cell-wall constituents (crude fiber or ADF) in the early weaning stage. The protective effect of fiber is explained through the stimulus of ileo-cecal motility, avoiding an excessive retention time (Cheeke, 1987; Lebas, 1989). According to Carabano et al. (1988), dietary fiber does not only play a dominant role in the regulation of the digesta flow but in determining the extent of cecal microbial proliferation as well. Their results suggest that in diets with a low fiber content (<10% CF or <13% ADF) only a relatively small proportion of cecal content is removed each day. Consequently, an increase of cecal volume and protein level is induced (Carabano et al., 1988). This cecal disequilibrium favourises the utilisation of protein as an energy source with deamination and increased ammonia production.

However, retention time of the digesta in the cecum is better related to indigestible fiber than to total fiber content (De Blas et al., 1992). Consequently, minimal dietary fiber requirements should be better established as indigestible crude fiber or ADF, as proposed by Lebas already more than 10 years ago. Concerning the nature of this fraction, dietary differences in lignin or hemicellulose were not related to the appearance of digestive disorders (Lebas et al., 1989; Maitre et al., 1990a).

An excess of dietary fiber is not desirable either because the DE content is dropping and a too high protein/energy ratio is commonly the result. Such a situation is favourable for the proteolytic flora producing ammonia with an increasing risk of digestive disorders (De Blas et al., 1981; Lebas, 1989). These effects are enhanced by using highly lignified fiber sources (De Blas et al., 1992). According to recent results obtained in their laboratory, inclusion of feedstuffs with a high proportion of digestible fiber has the opposite effect enhanced by the synergic effect with the digestive utilization of more indigestible sources of fiber (De Blas et al., 1992). Although the results are difficult to interpret, because many dietary components vary at the same time, there is no doubt that dietary fiber influences ileo-cecal motility and thus cecal retention time and fermentation.

According to Morisse et al.,(1989), a diet with a low starch and high indigestible fiber content reduces post-weaning mortality, when given already before weaning (from day 18 on). An increased pH and volatile fatty acid concentrations were found in the cecum when kits were 30 days old. They concluded that such a diet fed early, leads to a better intestinal equilibrium and a better protection against the development of pathogens. Post-weaning diarrhea is thus partly the result of the pre-weaning milk-feed intake pattern. Also a delayed start of kit's solid feed intake, results in a decreased weaning weight and an increased post-weaning mortality (Maertens & De Groote, 1990).

Taking into account the above discussed dietary recommendations, for highly productive does and kits, a problem occurs when kits start to take in solid feed. Because they receive the same feed, which diet do we have to use? Preference for the doe or for her kits? What happens with the doe if we change at day 18 to a "starter kit diet", with a low starch content, a low energy content and a high content of cell-wall constituents? We may expect that because of the low energy content, daily energy intake will be lower (Maertens & De Groote, 1988b; Castellini & Battaglini, 1991) and as a consequence milk production will drop the last week before weaning. For the kits this situation is not unfavourable if they compensate the loss of milk by an increased pellet intake. But if the doe's energy balance is very negative she will lose weight and be in a bad condition. Negative consequences for the further breeding career are to be feared as shown by Chmitelin et al.(1990). However, they used an extremely low starch diet (8%) and as a consequence the energy content would be lower than the mentioned (calculated) value. When a more balanced diet is fed from day 21 onward, weaning weight of kits and doe's condition were comparable when fed a reproduction diet till weaning date (Morisse et al., 1989). This is not surprising because rabbit kits are able to compensate the loss of milk by increasing solid feed intake (Maertens & De Groote, 1990). Early closing of the nest box stimulates them further to start solid feed intake (Maertens & De Groote, 1990).

As discussed above, primiparous does lose about 30% of their body energy during the first lactation (Parigi-Bini et al., 1990b), because their feed intake capacity is still limited (Castellini & Battaglini, 1991). For these does a low energy diet during the last week will emphasize this situation. To solve this problem it can be recommended to breed primiparous does semi-intensively (14d PP). Then they have a resting period.

A low starch, but cell-wall rich diet, does not necessarily imply a low energy diet. As indicated for does, rabbits digest fat in a way comparable to mono-gastric animals (Maertens et al., 1986; Partridge et al., 1986c; Santoma et al., 1987). Because rabbit milk is very rich in fat we may suppose that rabbit kits are well adapted to digest dietary fat. The use of added fat or of fat rich feedstuffs such as soybeans may ensure that the energy content of this diet is not too low.

2. FEED INTAKE REGULATION

Numerous studies have clearly demonstrated that the dietary energy content is the most significant factor controlling feed intake of rabbits (see reviews mentioned in the introduction). Rabbits try to adjust their voluntary feed intake in response to changes in dietary energy concentration. This regulation of intake, to achieve constant daily energy intake, is only possible at a DE concentration above 9.3 MJ, as was recently confirmed by Maertens et al., (1988a) and Partridge et al., (1989). However, in experiments wereby oil, fat or fatcontaining raw materials are used to increase the energy content, the daily DE intake sometimes tended to be higher. This tendency has been observed with fatteners (Santoma et al., 1987; Maertens et al., 1988a) and does as well (Maertens & De Groote, 1988; Fraga, et al., 1989, Castellini & Battaglini, 1991; Barge et al., 1991). It is not clear for does whether the increased daily DE intake is the result of the higher performance level or of the higher DE content. Furthermore it is difficult to interpret because other factors interfered as there were the added oil or fat.

However, it has recently been demonstrated that the dietary supplementation of animal fat and vegetable oil significantly improved the digestibility of other dietary nutrients (Fekete et al., 1990). This interaction was most pronounced in fat, crude fiber and N-free extract digestibility when using a low energy basal diet. Furthermore this synergistic effect was higher with sunflower oil than with animal fat. An inverse relationship between the digestibility of the fat and the saturated fatty acid content has also been demonstrated with rabbits (Maertens et al., 1986; Santoma et al., 1987) as in innumerable reports in the literature for poultry and pigs.

3. RAW MATERIALS

A very large range of feedstuffs and industrial by-products can be used in rabbit diets (Cheeke, 1987). Especially because of their specific fiber requirement, feedstuffs unuseful in diets of other species, are employed in rabbit feeding. Many experiments are conducted in order to study the tolerance or the effects of increasing inclusion levels on the performances of rabbits. Recent results with dehydrated feedstuffs are summarized in Table 3 (see appendix).

A lot of these experiments is difficult to interpret because of the changed amino acid balance or the discrepancies in energy content between the diets in study. In most of the experiments good results are obtained with the tested feedstuffs. However, some feedstuffs contain toxins (e.g. lupines) and a treatment is necessary before dietary incorporation. Sometimes the post-harvest treatment can alter the palatability or the protein quality with severe effects on zootechnical performances (Perez et al., 1990).

It is further confirmed that rabbits are able to utilize non-nitrogen protein (Gioffré et al., 1988; Singh et al., 1988) but biuret is utilized more efficiently than urea (Mathius et al., 1988). However, many studies have clearly demonstrated that dietary urea is hydrolysed before reaching the cecum (see Cheeke, 1987 or Lebas, 1989). Biuret is hydrolysed more slowly and might be more likely to reach the cecum to serve as a bacterial substrate. Consequently a higher efficiency is found and even with a low protein diet, a partly replacement of the dietary protein is possible without deteriorating results (Gioffré et al., 1988).

4. ENERGY EVALUATION

4.1. Energy system

Digestible energy (DE) is accepted world-wide as a good expression of the energy value of **compound feeds** (Cheeke, 1987; Santoma et al., 1989; Maertens & Lebas, 1989) for rabbits. The energy losses through the urine are limited and the magnitude with metabolizable energy (ME) is quite constant, as was recently confirmed by Ortiz et al. (1989). This is not surprising because the range in dietary protein content of commercially feeds is rather small (2 - 4%). Urinary N and consequent energy losses (Grandi & Battaglini, 1987) are related to the dietary protein content, because excess protein is metabolized as an energy source, with the nitrogen excreted as urea in the urine. The use of DE instead of ME overestimates the energy value of diets with an extreme high protein content, but this effect is neglectable under practical conditions.

However, more important in practical diets is to know if the use of DE instead of NE, as the dietary energy unit, provides a good estimate of the energetic utilization. Because of the relative important, and widely varying fiber content in rabbit diets and its effect on retention time and fermentation, effects on the efficiency of ME utilization have been shown. Ortiz et al., (1989) found a linear and negative relationship, implying an increase of total heat losses of .40% per each 1% increment of ADF. A higher fiber content in the diet implies that a high proportion of ME is derived to meet the energy requirements for digestive processes. However, the overestimating of the energetic utilisation of high fibrous diets (18-24% ADF) when using DE is rather low (5%)(Ortiz et al., 1989).

The use of DE instead of ME for **raw materials** can be more criticized. As mentioned above, energy lost in the urine is not constant but will depend of the surplus amino acid concentrations of the feedstuff. The energy lost in the urine is relatively small for cereals (2-3%) but high in protein concentrates (± 10%) (Batterham, 1990). Because protein content of raw materials is very divergent, protein rich feedstuffs are thus overestimated when using DE instead of ME. However, ME values are not additive. In order to overcome this problem, the values are corrected to a given nitrogen balance. We propose to use ME corrected to N equilibrium as in poultry nutrition (Maertens et al., 1990). The MEn system evaluates protein feedstuffs to a lower extent and pretends a more correct energy evaluation in order to compare raw materials.

A second disadvantage, when using DE values, is that the dietary protein content tends to increase. When formulating least cost diets, the protein restriction has a high cost increasing effect because energy cost is actually high compared to protein. This effect is enhanced by using DE values instead of ME values for raw materials. According to De Blas et al. (1981), dietary protein content should be restricted to keep the relationship DE/digestible crude protein above 22 kcal/g (or more commonly expressed as a protein to energy ratio of 10,8 g/MJ DE). An excess of dietary protein has been linked to an increase of post-weaning diarrhea mortality (Lebas, 1989).

However, MEn values are normally not determined but they can be approached using the DE and the digestibility of the protein. The energy content of urinary nitrogen amounts 30 KJ/g (Jentsch et al., 1963) or 4.8 KJ/g protein. The ME value, corrected for N equilibrium, is thus obtained by subtracting the amount of 4.8 KJ/g digestible protein from the DE content. In Table 4 some of the proposed energy values are given (Maertens et al., 1990).

Table 4. Proposed DE and MEn values of some commonly used feedstuffs in rabbit diets.
(Maertens et al., 1990)

Raw material	Crude protein (%)	Protein digestibility (%)	DE (MJ/kg)	MEn (MJ/kg)
Barley	11.9	65	12.50	12.15
Wheat	10.7	77	13.20	12.85
Lupin	30.9	84	13.65	12.40
Wheat middlings	16.1	77	10.80	10.25
Corn middlings	9.8	66	12.30	12.00
Corn gluten feed	21.2	75	11.85	11.10
Beet pulp	9.8	45	11.25	11.05
Cassava meal	2.8	40	12.05	12.00
Soybeans	36.5	85	17.80	16.35
Soybean meal	42.3	83	13.65	11.95
Sunflower meal	29.1	76	10.10	9.05
Blended animal fat	-	-	33.85	33.85
Alfalfa meal A	15.6	62	7.40	6.90
Alfalfa meal B	16.9	66	7.90	7.50
Wheat straw meal	3.5	50	2.70	2.60

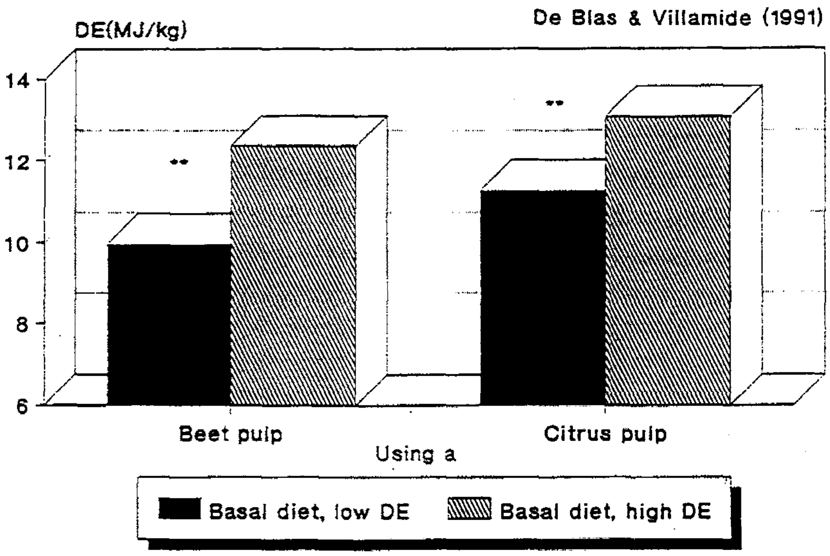
For more raw materials see Maertens et al. (1990)

4.2. Energy values of feedstuffs

As for other livestock, the available energy of feedstuffs is basic information in order to formulate least cost diets. As pointed out at the 4th WRSA Congress at Budapest, there is still a lack of useful data concerning the feeding value of feedstuffs (Maertens & Lebas, 1989). Significant efforts are done since then in order to evaluate/estimate the energy content of raw materials (Maertens et al., 1988b, De Blas et al., 1989; Villamide et al., 1989; Maertens et al., 1990; De Blas & Villamide, 1990; Villamide et al., 1991; Villamide & De Blas, 1991).

However, because of interactions with the basal diet (De Blas & Villamide, 1990), differences in DE content of more than 10% are found when assaying feedstuffs with highly digestible fiber (Fig. 4). They could be ascribed to the changed retention time of the digesta in the gut (Gidenne et al., 1987; Gidenne et al., 1990b). Fortunately, interactions between the feedstuff in study and the basal diet are limited (Maertens & De Groote, 1981, Villamide et al., 1991; Villamide & De Blas, 1991) to special feedstuffs (fats or feedstuffs rich in digestible fiber). However, to avoid the formulation of unbalanced experimental diet with very high or very low contents of fiber, it is necessary to use different basal diets according to the raw material in study (Maertens et al., 1988b; Santoma et al., 1989; Villamide et al., 1989). Because unbalanced types of diet would cause alterations in transit time and would lead to values that could not be extrapolated to normal diets.

Fig. 4. EFFECT OF TYPE OF BASAL DIET ON DE(MJ) OF CITRUS AND BEET PULP



Determined energy values of feedstuffs, will not always give a good estimate of the true energy content of the batch. Each batch of a feedstuffs risks to have a different chemical composition and consequently a different energy value. Many feedstuffs used as major components in rabbit diets have a very divergent composition (e.g. alfalfa meal, sunflower meal, wheat by-products). For an accurate feed formulation a correction of the table value in relation to the applied quality is required. Two approaches will be outlined:

a. Making use of the relationship between the digestible nutrients, and DE or ME content. Based on 81 mixed feeds, assayed at our laboratory (Maertens et al., 1988b), the following prediction equation was obtained:

   DE (MJ/kg) = 23.85 DCP + 37.78 DCfat + 16.28 DCF + 17.11 DNFE or adapted to
   MEn (MJ/kg) = 19.04 DCP + 37.78 DCfat + 16.28 DCF + 17.11 DNFE

Making use of these equations, the digestibity coefficients and the real chemical composition, it is possible to adapt the energy value to the batch available. Analyses in feed plants are done already to a large extent with near infrared reflectance spectroscopy (NIRS). Therefore the limitation to the use of these equations is that they are based on an accurate knowledge of the digestibility of the energy providing nutrients.

b. When a sufficient number of batches of the same feedstuff are assayed, regression equations involving various chemical fractions of the feedstuff can be drawn up.
The following equations are proposed:

Alfalfa meal: (Maertens et al., 1988b)
DE (MJ/kg DM) = 8.47 + 0.237 CP (g/kg DM) - 0.148 CF (g/kg DM) $R^2 = 0.76$
MEn(MJ/kg DM) = 8.47 + 0.199 CP (g/kg DM) - 0.141 CF (g/kg DM)

Protein concentrates: (Villamide et al., 1991)
DE (MJ/kg DM) = 18.79 - 0.034 CF (g/kg) + 0.019 EE (g/kg) $R^2 = 0.87$
DE (MJ/kg DM) = 24.08 - 0.024 CF (g/kg) + 0.016 EE (g/kg) - 0.098 ash (g/kg) $R^2 = 0.93$

The equations based on a single nutrient explain actually less than 75% of the observed variation in DE content.

The equations proposed for compound feeds (see reviews Santoma et al., 1989 or Xiccato, 1989) may not be used for feedstuffs because they do not cover the range of composition of single feedstuffs. The estimation does usually not supply precise data for raw materials (Maertens et al., 1988b; Villamide et al., 1991)

Further efforts are necessary to essay a sufficient number of batches of each feedstuff or of comparable feedstuffs. In this respect, a combined data set of the different laboratories can lead to a significant progress in predicting the energy values of feedstuffs based on their chemical composition.

5. FEED ADDITIVES

Last years, an increasing number of feed additives are offered for rabbit production. There will be emphasized on probiotics, ß agonists and some "other" additives.

Probiotics are dietary supplements containing beneficial live or revified micro-organisms. They are added to the diet with the intention of having these organisms to colonize the gut. Their mode of action is generally ascribed to their ability to stimulate the digestion process and/or to contribute to the microbial equilibrium of the gut in order to prevent digestive disorders and/or to increase zootechnical performances. Recent results with different types of micro-organisms have been reported in the literature for rabbits. Strains of *Lactobacillus*, *Streptococcus faecium*, *Bacillus*, yeasts or mixtures are used, especially with young and stressed animals (weanlings). Favourable effects are most pronounced in reducing mortality of weanlings although other zootechnical performances are sometimes significantly improved. Encouraging results have been reported with *Bacillus* CIP 5832 (Csikváry et al., 1990; Vörös et al., 1990; Duperray & Robertson, 1990), with *Streptococcus faecium* (Csikváry et al., 1990) and with a mixture of *Lactobacillus*, *Streptoccoccus faecium* and yeasts (Hollister et al., 1989 & 1990). However, as for other livestock (see review Van Belle et al., 1990) the results appear to be heterogeneous, irregular and not always positive. For example, with a dietary supplementation of 9.8x10⁵g *Bacillus subtillis* spores, Lambertini et al., (1990a) did not observe any effect on doe and fatteners performances as well. More research is necessary as there are: the exact mode of action, the resistance against digestive enzymes, their specific conditions of use, the associative effects of some strains, the complementarity with other additives.

Recently, the first reports have been published dealing with beta-adrenergic agents on rabbit performances. In contrast with probiotics, there is common agreement about the improvement of the zootechnical performances and carcass characteristics, when using **ß agonists**. A significant increased daily weight gain of at least 10 till 30% and a significant better feed efficiency is reported with cimaterol (Forsberg et al., 1989; Ali-Bar et al., 1991), clenbuterol (Parigi-Bini et al., 1990c; Corino et al., 1991; Pialorsi et al., 1992) as with salbutamol as well (Pialorsi et al., 1992). The favourable repartitioning effects observed with other livestock have been confirmed: an increase of dressing percentage, skeletal muscles weights and carcass protein content while fat content is dropping. Clenbuterol significantly ($p < 0.01$) improves the N balance (Parigi-Bini et al., 1990c; Corino et al., 1991). As in other livestock production, the use of these products has to be tolerated by the consumers, otherwise rabbit meat risks to lose the image of natural, high-quality meat.

Other dietary additives considered as "pro-probiotics" are the oligo-saccharides. These nonstarch polysaccharides are known for their favourable effects on human intestinal flora (decrease of *E. coli* and *C. perfrigens*, development of *lactobacillus* and *Bifidobacteria*)(Hidaka, 1986 cited by Morisse et al.,1990). Because of the weak microbial equilibrium in the gut of weanlings and rabbits' hindgut fermentation, these polysaccharides have a certain potential to protect rabbits against enteritis. First results are encouraging (Morisse et al., 1990) and have shown their beneficial effect on volatile fatty acid concentrations in the caecum, while caecal ammonia significantly ($p < 0.05$) dropped.

Flavors are promoted as a means of increasing feed intake. However, if there are no problems with the palatability of the diet they failed in their objective (Lambertini et al.,1990b). Probably they are more useful to ensure a constant dietary taste and aroma, especially because with least cost diet formulation the ingredient composition is changing rather frequently.

Although some conflicting results, dietary copper sulphate addition is used as growth promoter and to protect young rabbits against enterotoxemia (see Cheeke, 1987). These effects have been confirmed under different circumstances (Robinson et al., 1988; Bassuny, 1991), although dietary levels are very divergent. In some reports concerning copper supplementation it is also not clear if the mentioned levels refer to copper or copper sulphate.

6. DIETARY NUTRIENT RECOMMENDATIONS AND PRACTICAL FEEDING

As a conclusion dietary recommendations are summarized in Table 5. The number of different diets should be limited for different reasons. First of all, there is not sufficiently scientific evidence that each category or age needs a different diet and secondly because of practical considerations. More and more rabbit feeds are delivered in bulk, therefore sufficient quantities of each diet are necessary. Further automatic or semi-automatic feeding systems are more and more used in large units. Based on these practical considerations, recommendations will be distinguished only for three categories of rabbits: breeding does, young rabbits (3 - 6/7 weeks) and fatteners (6/7 - 10/11 weeks). On intensive farms these categories consume more than 90% of the total feed. Young parent stock, males and does in wait-gestation cages may also be fed with one of these rations, sometimes on a restricted basis.

In Table 5, recommended nutrient levels are limited, referring for more details to the comprehensive book of Cheeke (1987) or the regularly updated recommendations of Lebas (1989). Nutrient levels are given in such a way that they can be used as constraints in linear programming. At present, energy cost is high when compared to protein. Therefore only a minimum level of dietary energy content is given. Energy recommendations are in accordance with our proposed energy values for ingredients (Maertens et al., 1990).
Dietary bulk levels are given as a minimum to ensure a normal rate of passage of digesta throughout the digestive tract. Recommendation levels are for "the average rabbitry". When the health situation is very good, at a low infection pressure, fiber levels may be reduced and in accordance the energy content increased. Consequently a favourable feed-conversion ratio will occur.

Table 5. Some recommended nutrient levels in diets for intensively reared rabbits

Dietary composition (assuming a d.m. of 89 - 90%)		Reproducing does	Young rabbits	Fattening rabbits
Digestible energy	(MJ/kg)	>10.5	>9.5	9.8 - 10
	(Kcal/kg)	*>2500*	*>2250*	*2350 - 2400*
Metabol. energy	MJ/kg)	>10	>9.0	9.3 - 9.5
	(Kcal/kg)	*>2380*	*>2140*	*2240 - 2280*
Crude protein	(%)	17.5 - 18.0	15.5 - 16.0	16.0 - 16.5
Digestible protein	(%)	12.8 - 13.3	10.5 - 11.0	11.2 - 11.7
Crude fiber	(%)	>11.5	>15.5	>14.5
ADF	(%)	>15	>20	>18.5
Indig. crude fiber	(%)	>10.0	>14.0	>12.5
Crude fat	(%)	4 - 5	3 - 5	3 - 5
Lysine	(%	>0.9	>0.75	>0.7
Starch	(%)	free	<13.5	free
Coccidiostat		-	+	+
Probiotics		-	+	- / +

In commercial rabbitries, as a rule rabbits are fed on an *ad libitum* basis. This is not only for practical considerations but because of the rapid reproductive rates and the adjustment of the voluntary feed intake in response to changes in dietary energy density. However some categories are to be fed on a restricted basis to prevent extreme fattening. In Table 6 some practical feeding recommendations are given.

For young does, the feeding regime strongly depends on the age of the first desired mating. Although there exists common agreement in the literature that *ad libitum* feeding together with early mating (75-80% of adult weight) leads to favourable results in obtaining a first litter (see Maertens & Okerman, 1987), in practice, it is recommended to restrict young does and to postpone the first mating till the age of 18 weeks. This led to a longer reproductive live and a lower replacement level of does (Baumier, 1990). When young does are fed *ad libitum*, it seems preferable to use the fatteners diet (David & Lebas, 1989), which is normally less concentrated than the reproduction diet.

When restricted quantities are fed, they should be related to the weight of the rabbits, their body condition and to the dietary nutrient density. The recommended level of restricted feeding is usually 35 g/day/kg live weight. Especially when using males of heavy male lines, a certain restriction is advisable. This promotes their sexual drive and increases their resistance to sore hocks.

Table 6. Feeding - scheme for commercial rabbit meat production

Category	Quantity		Diet
Young does			
* early mating (15 - 16 weeks)	ad libitum		fatteners
* late mating (17 - 18 weeks)	restricted		fatteners
	(35 g/kg live weight)		
	followed by a 4 days flushing before mating		
Does			
* late gestation	ad libitum		lactation
* lactating	ad libitum	kits <3 weeks:	lactation
		kits >3 weeks:	weaning
* in wait-gestation cages	ad libitum		
except early pregnancy	restricted		fatteners
	35 g/kg live weight		
Males			
* young (till 18 weeks)	ad libitum		fatteners
* old	restricted		fatteners
	35 g/kg live weight		
Weaned rabbits			
* 3 - 6/7 weeks	ad libitum		weaning
* 6/7 - 10/11 weeks	ad libitum		fatteners

Based on the work of Szendrö et al., (1988), restricted feeding during the fattening period leads to a more efficient feed conversion when using restricted feeding time. This theory was recently confirmed (Schlolaut & Lange, 1990; Mc Nitt & Moody, 1991). However, beneficial effects are depending of age of fatteners, length of feeding time (at least 9 hours) and the time of feeding. It is emphasised that at least during the hours when rabbits spend the most time of eating (late afternoon and night) free access is necessary, to obtain normal weight gain. Furthermore the better feed conversion efficiency is partly false, because the comparison with *ad libitum* feeding should be done till the same finishing weight instead of the same finishing age. Because with limit feeding, even in the least restricted groups, daily weight gain is always lower (Schlolaut & Lange, 1990; Mc Nitt & Moody, 1991) and consequently feed efficiency is measured in a more favourable weight range. Restricted feeding has a lot of practical consequences; e.g. number of feeding places and extra work. However, with automatic feed distribution, restricted feeding time is possible (Cavani et al., 1991). But the first results indicates again that a reduced feed conversion was associated with a decreased daily weight gain (Cavani et al., 1991). Of interest is, that *ad libitum* fed rabbits showed a comparable daily feed intake and weight gain, when the diet was distributed once a day compared to 2 till 8 times daily. A slight tendency to a more favourable feed conversion efficiency was observed when fed different times (Cavani et al., 1991).

One should also keep in mind that a feed restriction during the first weeks after weaning seems not to be desirable, because it is associated with an increased retention time of digesta, a reduced cecal acidity, a rise of the ammonia concentration and a drop of the cecal fatty acid levels (Maertens & Peeters, 1988). Such cecal conditions are known as predisposing factors to diarrhea (Morisse et al., 1985).

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Table 3. Summary of papers concerning the use of raw materials in rabbit diets

Raw material	Dietary level	Substitution	Results	Authors
Alfalfa meal (after ensiling)	25 ; 50 %	of alfalfa meal	decreased intake and DWG, especially at 50 %	Perez et al., 1990
Azolla meal	11.5 % 23 %	of soybean meal of soybean meal	comparable with controls DWG, FE : significantly ↓	Gualtieri et al., 1988
Barley straw + sun-flower meal	43 % + 15 %	alfalfa hay (50 %) and wheat bran (8 %)	tendency for ↑ DWG, FE	Carabano et al., 1989
Barley (germinated)	75 or 150 g/day	feed supplement	DWG, FE : ↓	Amici, 1989
Birdsfoot trefoil	8 ; 16 ; 24 and 32 %	of alfalfa meal	DWG, FE : comparable	Grandi & Battaglini, 1988
Biuret	1.58 % 2.20 %	added to a low protein diet added to a low protein diet	DWG, FE, N-retention : = DWG : ↑	Gioffré et al., 1988 Mathius et al., 1988
Buckwheat	10 ; 20 ; 40 ; 60 %	isonitrogenous diets	DWG, FE : comparable	Tor-Agbidye et al., 1990
Chick-peas	20 %	barley + soya	DWG, FE : ↓ low protein quality	Alicata et al., 1991
Condensed cane molasses stillage	5 %	of diet	DWG, FE : ↑	Cavani et al., 1988b
Faba beans	10 %	diet (isonitrogenous)	DWG, FE : comparable	Maitre et al., 1990b
Faba beans + lupin	10 + 5 %	diet (isonitrogenous)	tendency for increased mortality	Maitre et al., 1990b
Grape seed meal	10 ; 20 %	alfalfa meal	FE lower at 20 % useful till 10 %	Cavani et al., 1988a
Full-fat sunflower seeds	10 ; 20 ; 30 %	isonitrogenous diets	depressed DWG and FE, enhanced by inclusion level	Balogun & Etukunde, 1991

Raw material	Dietary level	Substitution	Results	Authors
Lupin	10 %	isonitrogenous diets	comparable DWG and FE	Maitre et al., 1990b
Lupin seed	10 ; 20 ; 30 ; 50 ; 62.5 %	isonitrogenous diets	only at the levels of 50 and 62.5 % decreased DWG	Kelly et al., 1990
Lupin (white)	8 ; 16 % extruded or not	isonitrogenous diets	non-extruded : decreased zootechnical performances	Battaglini et al., 1991
Peas	9 % 18 %	isonitrogenous diets isonitrogenous diets	DWG, FE : ↑ DWG, FE : comparable	Castellini et al., 1991
Sorghum (low tannin content)	?	barley	DWG, FE, DP : comparable	Gualtieri & Rapaccini, 1991
Rice hulls	2,5 ; 5 ; 10 ; 20 ; 30 %	isonitrogenous diets	optimal DWG, FE at 10 % inclusion	Raharjo et al., 1990
Sodium bentonite	3 ; 6 %		zootechnical result : = changed caecal mineral content	Lambertini et al., 1989
Sunflower meal	20 ; 35 ; 45 %	± isonitrogenous diets	DWG, FE : comparable	Masoero et al., 1990
Triticale	30 %	barley	DWG, FE : comparable Digestibility ↑ than barley	Bonanno et al., 1990
Tomato waste	20 %	alfalfa meal	FE : ↑	Alicata et al., 1988
Urea	1.5 % 1.8 %	isonitrogenous isonitrogenous	DWG, FE : comparable Performances of does ↓	Singh et al., 1988 Mathius et al., 1988
Whey (dehydrated)	5 ; 10 ; 20 %	isonitrogenous	Age depending : weanl.: DWG ↑ mortal. ↑ fatteners : =	Coppings & Ekhator, 1990

DWG : daily weight gain FE : feed efficiency DP : dressing percentage

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