Reprod Nutr Dev (1996) 36, 191-203

Original article

The response of highly productive rabbits to dietary sulphur amino acid content for reproduction and growth

E Taboada [1], J Mendez [1], JC de Blas [2*]

[1] *COREN SCL, avda Juan XXIII 33, 32003, Orense;*
[2] *Departamento de Producción Animal, ETSI Agrónomos, Universidad Politécnica, 28040 Madrid, Spain*

(Received 28 August 1995; accepted 12 January 1996)

Summary — This study investigated the sulphur amino acid (SAA) requirements of rabbits. Five diets, containing 0.48–0.72% crude SAA, were formulated by supplementing a basal diet with DL-methionine. The apparent methionine digestibility (%) was 71.4 ± 1.1 in the basal diet and 102.9 ± 0.9 for DL-methionine, as estimated by the difference method. Feeding trials were carried out using 370 rabbit does and 1 195 weanling rabbits slaughtered at 2–2.1 kg body weight. Milk production was measured in 80 lactations. Carcass traits were determined in 125 rabbits. The dietary SAA content affected several productive traits, such as milk production, parturition interval, growth rate, carcass quality and feed efficiency. When the diets were compared using orthogonal contrasts, a minimum requirement of 0.54% crude or 0.40% digestible SAA was determined. Further responses in performance were observed, however, when the data were analysed by regression methods. The values of crude and digestible SAA for optimal production were, respectively, 0.63 and 0.49% (rabbit does) and, at least, 0.72 and 0.58% (growing rabbits).

sulphur amino acid requirement / methionine digestibility / reproductive performance / growth performance / rabbit

Résumé — Réponse de lapins hautement productifs au contenu de l'aliment en acides aminés soufrés pour la reproduction et la croissance. *L'objet de cette expérience était de mesurer les besoins du lapin en acides aminés soufrés (AAS). Les teneurs en AAS des cinq rations utilisées variaient entre 0,48 et 0,72 %. Elles ont été préparées à partir d'une ration de base complémentée avec de la DL-méthionine. La digestibilité apparente (%) était de 71,4 ± 1,1 pour la ration de base et 102,9 ± 0,9 pour la DL-méthionine, estimée par la méthode des différences. Pour la réalisation des essais d'alimentation, 370 lapines et 1 195 lapereaux sevrés ont été utilisés. La production laitière a été contrôlée dans 80 lactations. La qualité des carcasses a été déterminée chez 125 animaux. Les teneurs en*

* Correspondence and reprints

AAS des rations ont eu des effets sur certains facteurs de production, tels que la production laitière, l'intervalle des mises bas, le taux de croissance et l'efficacité alimentaire. Lorsque les régimes utilisés ont été comparés suivant le test de contrastes orthogonaux, une teneur minimale en AAS brutes et digestibles de 0,54 et 0,40 %, respectivement, a été déterminée. Par ailleurs, les réponses additionnelles des rendements ont été observées lorsque les données ont été analysées par la méthode de régression. En utilisant cette méthode, les teneurs optimales en AAS brutes et digestibles ont été, respectivement, de 0,63 et 0,49 (chez les lapines), et, au moins, de 0,72 et 0,58% (chez les lapereaux en croissance).

acides aminés soufrés / digestibilité de la méthionine / aliment de reproduction / aliment de croissance / lapins

INTRODUCTION

The sulphur amino acid (SAA) requirements of rabbits have been studied by several authors (Cheeke, 1971; Adamson and Fisher, 1973; Colin, 1975; Colin and Allain, 1978; Spreadbury, 1978; Schlolaut et al, 1981; Berchiche and Lebas, 1994). Practical recommendations vary from 0.45 to 0.63% SAA (as-fed basis). Part of this variation can be explained by differences in the methods used (purified vs commercial diets), the growth rate of the animals (20–40 g/day), the availability of the amino acids from the sources used and the energy concentration of the diets (2 250–2 670 kcal of digestible energy (DE)/kg). The authors know of no previous studies concerning SAA requirements of rabbit does. Furthermore, methionine and cystine digestibilities depend on the source of dietary protein, as in other non-ruminant species. For these reasons, the recommendations should be expressed on the basis of digestible, rather than crude, SAA in the diet.

Current feeding standards for rapidly growing rabbits and highly productive rabbit does recommend (on an as-fed basis) dietary crude sulphur amino acid contents greater than 0.60 and 0.55%, for DE concentrations of 2500 and 2600 kcal/kg respectively (Lebas, 1990).

The aim of this work was to: i) determine the apparent faecal digestibility of synthetic DL-methionine as compared to that of the methionine in a basal diet; and ii) measure the performance response of highly productive does and growing rabbits to an increase in dietary SAA content, by using five isoenergetic diets (2570 kcal DE/kg) with crude methionine and sulphur amino acids levels ranging from 0.24–0.48 and 0.48–0.72% respectively.

MATERIALS AND METHODS

Diets

A basal diet (diet A) was formulated to meet or exceed all the essential nutrient requirements for lactating does according to Lebas (1990), except for methionine and SAA, whose contents were limited to 0.24 and 0.48% respectively (as-fed basis). Four additional experimental diets (B, C, D and E) were made by supplementing the basal diet with DL-methionine, such that crude methionine or SAA contents were 0.30, 0.37, 0.41 and 0.48 or 0.54, 0.61, 0.65 and 0.72% (as-fed basis) respectively. The ingredients and chemical composition of the basal diet are shown in table I.

Digestibility trial

A group of 18 growing New Zealand x Californian rabbits, 45–60 days of age and weighing 1.6–1.8 kg, were randomly allotted to diets A and E to determine the apparent digestibilities of the dry matter, energy, neutral detergent fibre, protein, methionine and SAA in the basal diet, and the

Table I. Ingredients and chemical composition of the basal diet.

Ingredients	*%*
Lucerne meal	35.0
Barley grain	17.3
Wheat bran	15.9
Soybean meal-44	9.5
Barley rootlets	6.0
Sugar beet pulp	5.0
Wheat straw	4.2
Molasses	2.0
Pork lard	2.6
Dicalcium phosphate	1.6
Sodium chloride	0.49
Choline chloride	0.03
L-lysine	0.04
Robenidine premix[a]	0.10
Threonine-C	0.02
Vitamin/mineral mix[b]	0.18
Chemical analysis	*% DM*
Dry matter	90.6
Ash	9.5
Crude protein	17.2
Methionine	0.26
Sulphur amino acids	0.53
Starch	17.9
Ether extract	5.2
Crude fibre	15.3
Acid detergent fibre	17.2
Neutral detergent fibre	34.6
Acid detergent lignin	3.7
Calcium	1.3
Phosphorus	0.7
Gross energy, kcal/kg DM	4 401

[a] 6.6% of active ingredient. [b] Provided by Colborn Dawes SA. Mineral and vitamin composition (g/kg): Mn, 13.4; Zn, 40; I, 0.7; Fe, 24; Cu, 4; Co, 0.35; riboflavin, 2.1; calcium pantothenate, 7.3; nicotinic acid, 18.7; vitamin K_3, 0.65; vitamin E, 17; thiamine, 0.67; pyridoxine, 0.46; biotine, 0.04; folic acid, 0.1; vitamin B_{12}, 7 mg/kg; vitamin A, 6 700.000 IU/kg; vitamin D_3, 940 000 IU/kg.

digestibility of methionine and SAA in diet E. Following a ten-day period of adaptation to each diet, the animals were housed in metabolism cages that allowed the separation of faeces and urine. Collections were made on four consecutive days. The faeces produced daily were collected in polyethylene bags and stored at –20 °C. Coprophagy was not prevented.

Lactation trial

Eighty rabbit does (16 per diet) were used to measure milk production (one lactation per doe). Litter size varied from 7 to 14. The does were separated from kits after parturition and milk production was estimated daily from the weight loss of does during suckling. Feed consumption by does and kits was recorded respectively every ten days and from 21 days of age until weaning.

Another 370 New Zealand x Californian doe rabbits (74 per diet) were grouped by initial weight and number of previous parturitions, and randomly allotted to the five diets. An adaptation period (60 days) was allowed before beginning to record the rabbit performance over a five-month production cycle. Some data were disregarded during the experiment because of lack of fertility, disease or mortality. Therefore, only the data from 210 does with at least three lactations controlled during the experimental period were analysed. Males were included to give a female:male ratio between 8:1 and 7:1 throughout the experiment. The experimental diets were offered ad libitum in late pregnancy (from day 28 on) and throughout lactation; all other animals received a restricted amount of a commercial diet (140 to 150 g/day). The remating interval after parturition was fixed at 7 days and the weaning age at 30 days. Does that failed to conceive or lost all their kits were immediately given the opportunity to remate. Productive traits (parturition interval, prolificacy, kit mortality, litter weight at 21 days, litter weight at weaning and replacement rate of does) were recorded and accumulated per cage. Numerical productivity over a one-year production cycle was estimated as the number of kits weaned per cage in the experimental period (five months) x 12/5. The feed consumption and weight of does were recorded at the beginning and at the end of the experimental period.

The animals were housed in flat-deck cages measuring 600 x 500 x 330 mm. A cycle of 16 h light and 8 h dark was used throughout the experiment. Building heating systems and forced ventilation with cooling systems allowed the temperature to be maintained between 18 and 23 °C.

Growth trial

One hundred and forty six litters (1 195 rabbits) were assigned at random to the treatments. The rabbits received the experimental diets from 21 days of age until weaning (30 days). This was considered as a diet adaptation period, which permitted the extrapolation of the results to farms that use a single feed for both the does and the growing animals. After weaning, the rabbits were given ad libitum access to the same feed they received during the lactation period. One thousand animals were fattened in groups (eight rabbits per cage) for 40 days, whereas 195 rabbits were blocked by litter and grown in individual cages until they reached 2 kg body weight. Feed intake and length of the experimental period were recorded per cage.

The animals were housed in flat-deck cages measuring 600 x 250 x 330 mm high (individual cages) or 600 x 500 x 330 mm high (commercial cages). A cycle of 8 h light and 16 h dark was used throughout the experiment. Building heating systems and forced ventilation with cooling systems allowed the temperature to be maintained between 18 and 23 °C.

Carcass composition trial

One hundred and twenty five rabbits (twenty five per diet) choosen at random from the groups grown in commercial cages (eight rabbits per cage) were used. The animals were identified at the start of the trial and their growth rate was recorded individually. Once they had reached 70 days of age they were fasted for 2 h and transported to a commercial slaughterhouse. Transport and waiting times were respectively 2 and 1 h. Following a 90-minute air-drying period, the carcass dressing percentage (excluding gastrointestinal tract, skin, blood, tail and feet) was measured. The total weight of primal joints (fore and hind legs, loin and kidneys) was also determined.

Analytical methods

Chemical analysis of diets was conducted using the methods of Van Soest (1963) for acid detergent fibre and acid detergent lignin, Robertson and Van Soest (1981) for neutral detergent fibre, Longstaff and McNab (1986) for starch and AOAC (1984) for dry matter, ash, crude protein, ether extract and crude fibre. The gross energy was determined by adiabatic bomb calorimetry. The amino acid contents were determined by high pressure liquid chromatography (Cohen et al, 1989).

Statistical analysis

Data were analysed in a completely randomized block design using the GLM procedure of SAS (1985) with the initial parity number and initial weight of does as linear covariates and the type of diet as the main source of variation. Weaning weight was used as a linear covariate in the individual and collective growth trials analyses. Data are presented as least-squares means. Interactions between the type of diet and day or week of lactation were studied using a repeated measures analysis. Mean comparisons were made using orthogonal contrasts. Treatment sums of squares were partitioned into linear and quadratic effects.

RESULTS

Digestibility trial

The dry matter, NDF, protein and energy digestibilities (%) and digestible energy content (kcal/kg, as-fed basis) of the basal diet were (mean ± standard error): 64.9 ± 1.0, 31.6 ± 2.0, 71.8 ± 2.7, 63.5 ± 1.3, and 2 571 ± 57 respectively. The apparent faecal methionine digestibilities (%) in the basal diet and in diet E were 71.4 ± 1.1 and 87.2 ± 0.3 respectively. From these values, the digestibility of the supplementary DL-methionine was calculated by difference, obtaining an estimate of 102.9 ± 0.9%. The faecal apparent SAA digestibilities in diets A and E were 71.3 ± 1.1 and 81.3 ± 0.5 respectively.

Lactation trial

The dietary SAA content had a quadratic effect on the total and maximal milk production per doe (table II). The regression equations obtained between these variables were:

$$MP = -2.7 + 26.6\ SAA - 20.1\ SAA^2;$$
$$(\pm 4.3)\quad (\pm 14.2)\quad (\pm 11.7)$$
$$P = 0.01,\ n = 80$$

$$MP_{max} = -361 + 2103\ SAA - 1669\ SAA^2;$$
$$(\pm 210)\quad (\pm 699)\quad (\pm 574)$$
$$P = 0.002,\ n = 80$$

where MP = total milk production (kg/lactation), MP_{max} = maximal milk production (g/day), and SAA = crude dietary SAA content (%). According to these equations, the total and maximal milk production would be maximized for crude SAA levels in the diet of respectively 0.66 and 0.63%. However, no significant response of milk production to an increase of dietary SAA content was found beyond a level of 0.61% (table II).

A significant interaction ($P = 0.004$) was found between the type of diet and week of lactation on milk production (table II). Differences among diets were higher from day 7 up to day 20, which coincides with the period of maximal milk production (fig 1). However, the type of diet did not affect milk production in the fourth week of lactation (table II).

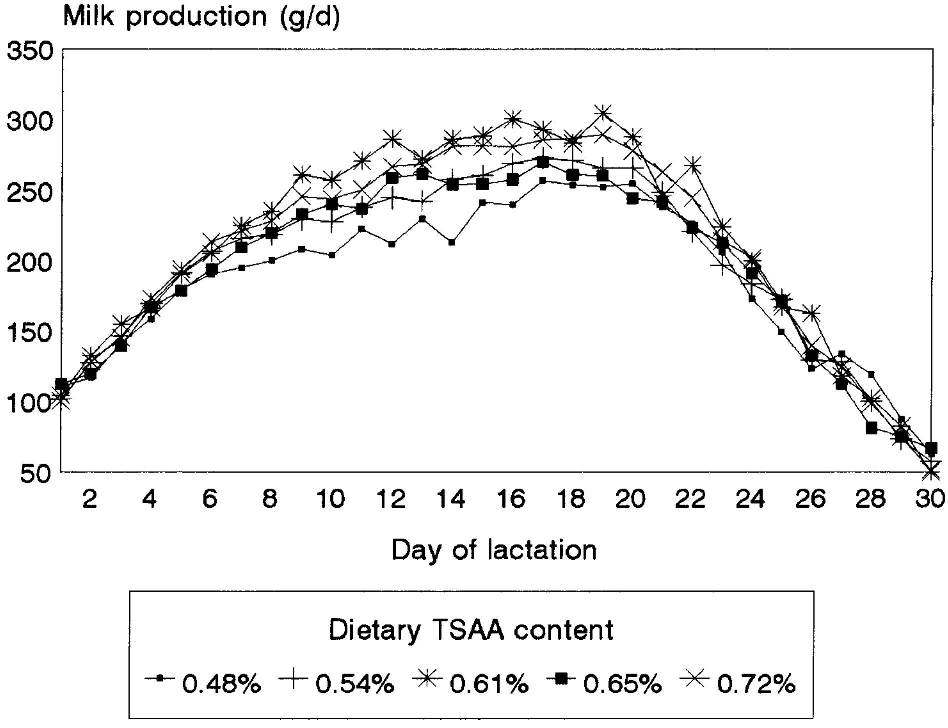

Fig 1. Effect of diet and day of lactation on daily milk production.

Table II. Effect of dietary SAA content on average milk production of does per lactation (least squares means).

Item	*Diet* [a]					*SE* [c]	P [d]	*Significance of comparison* [b]			
	A	*B*	*C*	*D*	*E*			*1*	*2*	*3*	*4*
Total milk production per doe (kg)	5.59	5.81	6.44	6.23	6.26	0.19	0.02	0.014	0.03	NS	NS
Weekly milk production (kg)											
Week 1	1.09	1.17	1.19	1.18	1.18	0.04	NS	0.07	NS	NS	NS
Week 2	1.49	1.66	1.88	1.79	1.81	0.05	0.001	0.001	0.004	NS	NS
Week 3	1.74	1.85	2.00	1.88	1.98	0.06	0.017	0.007	NS	NS	NS
Week 4	1.13	1.18	1.22	1.16	1.21	0.06	NS	NS	NS	NS	NS
Litter size at weaning	9.42	9.29	9.40	9.27	9.35	0.42	NS	NS	NS	NS	NS
Maximal milk production per day (g)	277	300	326	321	309	9	0.009	0.002	0.09	NS	NS
Day of lactation of maximal milk production	18.1	17.3	16.6	17.5	17.1	0.6	NS	NS	NS	NS	NS

[a] SAA contents of diets A, B, C, D, E: 0.48, 0.54, 0.61, 0.65 and 0.72% respectively. [b] 1: Diet A vs the other diets; 2: diet B vs diets C, D, E; 3: diet C vs diets D, E; 4 = diet D vs diet E. [c] SE = Standard error of means ($n = 16$); [d] P = level of significance; NS = not significant ($P > 0.10$).

The number of kits per litter at weaning (studied as a covariate) also had a significant effect ($P = 0.005$) on both total and maximal milk production, which increased by 165 g and 8 g/day respectively per each additional rabbit weaned. No significant interaction was found between the type of diet and the week of lactation on feed intake (fig 2). None of the variables studied affected the day of lactation on which peak of milk production was reached, although it tended to be earlier for diet C (16.6 days) than for the other diets (17.5 days). Feed intake by kits between 21 days and weaning was not affected by the type of diet and averaged 1829 ± 60 g per litter.

The effect of the type of diet on several productive parameters is shown in table III. The dietary SAA content did not affect either the average weight of the does or their weight gain during the experimental period, which averaged 3.95 kg and 0.03 g/day respectively. A comparison of the means of the total feed intake (does + kits) among the diets did not show significant differences, but this trait was affected quadratically ($P = 0.02$) by the dietary SAA content, having a maximum for a SAA level of 0.61%.

The parturition interval decreased ($P = 0.001$), by 11.5% or 6.5 days on average, from diet A to the other diets. The dietary SAA content had a quadratic effect ($P = 0.003$) on this trait, showing a minimum for a level of 0.63%. The type of diet did not affect the litter size at birth, number of kits born dead, mortality during the lactation period, litter size at weaning, or the replacement rate of does. Accordingly, the effect of diet on numerical productivity over a one-year production cycle followed a similar

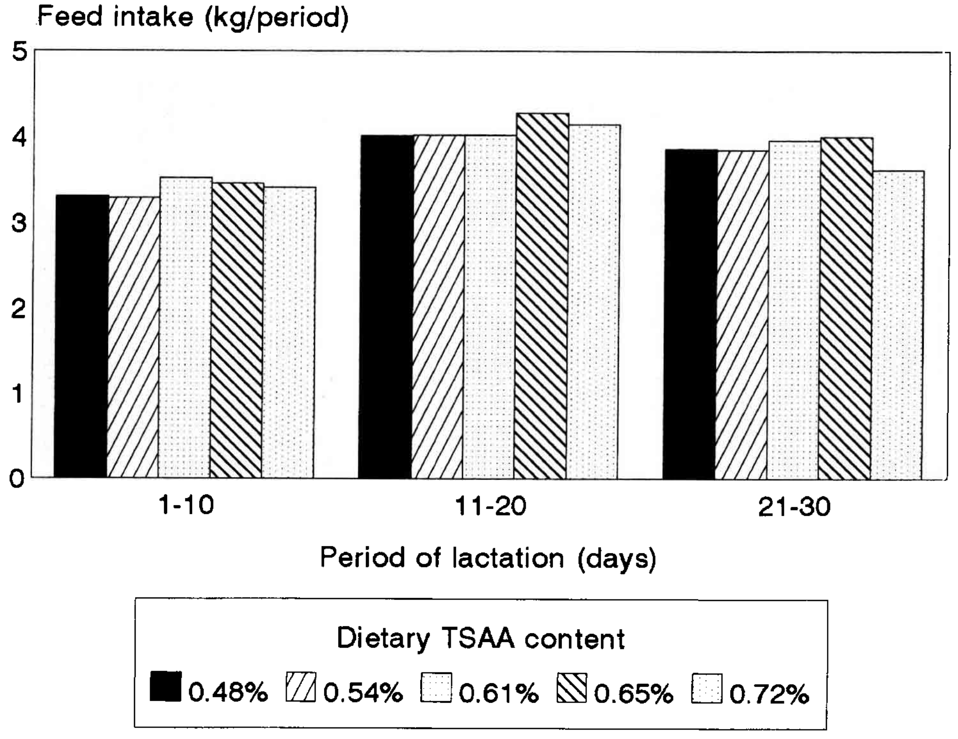

Fig 2. Effect of diet and period of lactation on feed intake of does.

Table III. Effect of dietary SAA content on productive traits of doe rabbits.

Item	*Diet* [a]					*SE* [c]	P [d]	*Significance of comparison* [b]			
	A	*B*	*C*	*D*	*E*			*1*	*2*	*3*	*4*
Average weight of does (kg)	3.94	3.99	3.91	3.92	3.99	0.05	NS	NS	NS	NS	NS
Live weight gain (g/day)	0.27	0.68	–0.30	–0.63	0.15	0.54	NS	NS	NS	NS	NS
Feed intake (g/day)	330	353	348	358	339	10.1	NS	NS	NS	NS	NS
Parturition interval (days)	55.5	49.2	48.5	48.1	50.6	1.51	0.006	0.0004	NS	NS	NS
No born alive per litter	9.83	9.96	10.1	10.1	10.1	0.27	NS	NS	NS	NS	NS
No born dead per litter	0.49	0.40	0.49	0.55	0.57	0.11	NS	NS	NS	NS	NS
No weaned per litter	8.26	8.10	8.48	8.34	8.18	0.18	NS	NS	NS	NS	NS
No weaned per cage and year	56.7	62.3	66.0	65.3	61.3	2.25	0.04	0.008	NS	NS	NS
Litter weight at 21 days (kg)	2.72	2.80	2.97	2.87	2.83	0.06	NS	0.06	NS	NS	NS
Litter weight at weaning (kg)	5.35	5.40	5.51	5.54	5.28	0.15	NS	NS	NS	NS	NS
Feed efficiency (kg weaned/kg feed)	0.302	0.322	0.340	0.334	0.329	0.01	0.10	0.01	NS	NS	NS
Feed efficiency (no weaned/kg feed)	0.469	0.486	0.525	0.507	0.519	0.02	0.10	0.05	NS	NS	NS
Replacement rate per doe and year (%)	102.6	120.7	107.8	102.6	113.1	10.96	NS	NS	NS	NS	NS

[a] SAA contents of diets A, B, C, D, E: 0.48, 0.54, 0.61, 0.65 and 0.72% respectively. [b] 1: Diet A vs the other diets; 2: diet B vs diets C, D, E; 3: diet C vs diets D, E; 4 = diet D vs diet E. [c] SE = Standard error of means ($n = 42$, except $n = 74$ in replacement rate); [d] P = level of significance; NS = not significant ($P > 0.10$).

trend to that of parturition interval, being 11.0% lower (56.7 vs 63.7 rabbits weaned per cage and year, $P = 0.008$) for diet A than for the average of the other four diets. Furthermore, the dietary SAA content affected ($P = 0.008$) numerical productivity quadratically, and would have reached a maximum value for an SAA level of 0.63%.

An increase in the crude dietary SAA content tended to quadratically affect litter weight at 21 days of age as a consequence of its effect on the milk production of the does. The regression equation obtained was:

$$\underset{}{LW21} = \underset{(\pm 1.42)}{0.44} + \underset{(\pm 4.76)}{7.60}\,SAA - \underset{(\pm 3.94)}{5.91}\,SAA^2; \quad P = 0.06,\ n = 210$$

where LW21 = litter weight at 21 days (kg). According to this equation, this trait would be maximized for a dietary SAA content of 0.64%. The litter weight at weaning tended to follow the same trend, although neither the differences among the diets nor the regressions reached significance levels in this case.

Feed conversion rate, both when expressed as kg and as the number of rabbits weaned per kg of feed (does + kits), was 10% lower for diet A than for the average of the other four diets. A minimum level of dietary SAA of 0.54% would therefore be required to obtain a high feed efficiency. On the other hand, the feed conversion rate increased linearly ($P = 0.05$) with dietary SAA content above this level.

Growth and carcass trials

The effect of diet on growth and carcass traits is shown in table IV. Rates of growth and feed conversion were significantly higher ($P < 0.001$) when the rabbits were grown in individual vs commercial cages (respectively 40.5 vs 35.7 g/day, SE = 0.35, and 0.361 vs 0.328 g gain/g feed, SE = 0.0034). No interaction was found between the type of diet and cage density for any of the traits under study.

The average daily gain during the whole fattening period increased ($P = 0.001$) by 5% from diet A to diets B, C, D and E, both in the individual and in the collective trial. No significant differences among the treatments were found above diet B, although the average daily gain increased linearly ($P < 0.001$) by 2% per each 0.1% increment in dietary SAA. When comparisons were made in the two-week postweaning period, significant responses were found up to a higher level of dietary SAA (diet C, each 0.61%). The quantitative response of daily gain to an increase in SAA content in the diet was also higher in this period than in the whole fattening period.

No significant differences were found among the diets for feed conversion rate in the individual fattening trial. In the collective trial, however, diet A showed a higher feed conversion rate (0.342 vs 0.324 g gain/g feed, $P = 0.07$), and a lower mortality (4.0% vs 9.5%, $P = 0.01$) than the other four diets. A lower feed efficiency for diet A (0.483 vs 0.502, $P = 0.03$) was found when comparisons among diets were made in the two-week postweaning period.

The carcass dressing percentage and proportion of primal joints in the carcass tended ($P = 0.06$ and 0.006) to increase linearly, by 1.73 and 2.67% respectively per 0.1% increment of dietary SAA.

DISCUSSION

The difference observed between the methionine digestibility in the basal diet and the digesibility estimated for DL-methionine (71.4 vs 102.9%) emphasizes the need to use digestible rather than crude units for expressing SAA requirements, as they

Table IV. Effect of dietary SAA content on growth and carcass traits.

Item	*Diet* [a]					*SE* [c]	P [d]	*Significance of comparison* [b]			
	A	*B*	*C*	*D*	*E*			*1*	*2*	*3*	*4*
Two-week postweaning period											
Average daily gain (g)	40.4	44.3	45.8	46.4	47.5	0.76	0.001	0.001	0.01	NS	NS
Feed efficiency (g gain/g feed)	0.483	0.495	0.508	0.494	0.511	0.008	NS	0.03	NS	NS	NS
Whole individual fattening trial											
Average daily gain (g)	38.2	40.4	40.8	41.2	41.9	0.57	0.003	0.001	NS	NS	NS
Feed efficiency (g gain/g feed)	0.356	0.369	0.363	0.357	0.367	0.004	NS	NS	NS	NS	NS
Length of fattening period (days)	38.3	36.1	36.0	35.4	34.9	0.52	0.001	0.001	NS	NS	NS
Collective fattening trial											
Average daily gain (g)	34.4	35.4	35.8	36.1	36.6	0.41	0.008	0.001	NS	NS	NS
Feed efficiency (g gain/g feed)	0.342	0.320	0.323	0.321	0.332	0.009	NS	0.07	NS	NS	NS
Total mortality (%)	4.0	10.0	7.5	12.0	8.5	0.019	0.05	0.01	NS	NS	NS
Carcass traits											
Carcass dressing percentage (%)	56.5	56.8	56.8	56.8	57.3	0.29	NS	NS	NS	NS	NS
Proportion of primal joints in dressed carcass (%)	83.2	83.2	83.5	83.7	83.8	0.18	0.08	NS	0.05	NS	NS

[a] SAA contents of diets A, B, C, D, E: 0.48, 0.54, 0.61, 0.65 and 0.72% respectively. [b] 1: Diet A vs the other diets; 2: diet B vs diets C, D, E; 3: diet C vs diets D, E; 4 = diet D vs diet E. [c] SE = Standard error of means (n = 39 for individual growth, n = 25 for collective growth and carcass traits except n = 200 for mortality); [d] P = level of significance; NS = not significant ($P > 0.10$).

would not be accurately estimated when extrapolating the results to diets with different levels of supplementary synthetic methionine.

This experiment indicated that the dietary SAA content affected, in the interval studied, several traits in highly productive rabbit does, including parturition interval, numerical productivity, milk production, litter weight at 21 days of age and feed efficiency. No significant improvements in these traits were found beyond diet B, which implies a minimal requirement level of 0.54% crude or 0.40% digestible SAA for a good performance. Further improvements of these traits (from 5.6 to 8.0%) were found when the data were analysed using regression methods. Using this approach, optimal dietary crude and digestible SAA levels were approximately 0.63 and 0.49% respectively. Current feeding standards of crude SAA (0.55%, Lebas, 1990) for rabbit doe diets of similar DE content (2 600 kcal) are closer to the minimum rather than the optimal values obtained in this work. On the other hand, Schlolaut et al (1981) did not observe any reproductive difference in rabbit does, using two diets with low (0.42) and high (0.77%) contents of SAA. This work seems to indicate that an excess of dietary SAA results in a lower reproductive performance.

Like the changes in doe performance, the average daily weight gain did not increase for diets containing more than 0.54 or 0.40% crude or digestible SAA respectively. Further linear increases, however, in daily gain, carcass dressing percentage and proportion of primal joints in the carcass were found throughout the interval studied. Average values for these traits were 3.5, 0.9 and 0.7% higher in diet E than in diet B. Accordingly, optimal values of crude and digestible SAA for maximal fattening performance should be, at least, 0.72 and 0.58% respectively. Furthermore, both the minimal SAA requirements and the response of rate of growth to dietary SAA content, were higher in the first two weeks than over the whole fattening period. This suggested that SAA requirements decreased with age. This effect was not observed in a previous study on lysine requirements (Taboada et al, 1994).

The type of diet had little effect on the feed conversion rate, as the feed intake varied in parallel with the daily gain. This agrees with recent observations made by Berchiche and Lebas (1994). These results are surprising, as a higher feed efficiency might be expected for diets with a better equilibrium among essential amino acids, which, furthermore, led to higher growth rates. However, an increase of dietary SAA might also lead to an increase in body fat. In this way, Berchiche and Lebas (1994) and Berchiche et al (1995) observed an increase in the weight of kidney fat in parallel with an increase in growth rate, when supplementing a SAA-deficient basal diet with different levels of DL-methionine. The higher efficiency obtained for diet A in the collective fattening period might be explained by the lower level of mortality observed for this diet.

The current feeding standards for crude SAA in growing-diets containing 2 570 kcal DE/kg is 0.62% (Lebas, 1990). This value is higher than the minimum (0.54%), but lower than the optimal (>0.72%) requirement obtained in this study. Berchiche and Lebas (1994) also determined an optimal concentration for crude SAA of 0.62% for diets containing 2 670 kcal DE/kg. Further supplementation with DL-methionine (up to 0.67%) led to a decrease of growth rate and feed intake, although the carcass-dressing percentage continued to increase. The final weight at the end of the fattening period in that work, however, was established to be 2.5 kg, whereas in this study it was 2 kg (individual fattening trial) or about 2.1 kg (collective fattening trial). Part of the difference again might be explained by a decrease in SAA requirements with age. Furthermore, the methionine content in the basal diet was lower (0.37 vs 0.48%), and the proportion of supplementary DL-methionine at the same level of total SAA was higher in the work by Berchiche and Lebas than in this study. Accordingly, at the same dietary SAA content, the methionine and SAA digestibilities should be higher in that work than in this study, accounting for part of the lower crude SAA requirements observed.

The minimal requirement for digestible SAA was 66.7% of the digestible lysine requirement obtained in a previous study (Taboada et al, 1994). This value compares well with the 62% SAA:lysine ratio observed by Moughan et al (1988) in the whole body of 53-day-old New Zealand rabbits. According to these authors, the methionine:SAA ratio in the body of young rabbits is 33%. In the same way, Colin (1978) determined that cystine may represent 65% of the SAA content without affecting the performance of growing rabbits. The minimal proportion of methionine in the total SAA requirement is therefore much lower than observed in other species, which could be explained by the high proportion of fur in the rabbit body and its high cystine content. Although more information is needed about this point for rabbit does, this ratio may serve to enable calculation of methionine from the total SAA requirements.

CONCLUSION

According to the results of this work, a minimal concentration of 0.54 crude or 0.40% digestible SAA should be included in the diets of both does and growing rabbits to produce good performance and feed efficiency. Further improvements in several productive traits were obtained when the crude and digestible SAA were increased to levels of 0.63 and 0.49% (rabbit does) and 0.72 and 0.58% (growing rabbits) respectively. The results suggest that the SAA requirements of growing rabbits decrease with age. The optimal concentrations should be chosen within these intervals, according to the current prices of SAA and rabbit meat. The results of this study also demonstrate the need to use digestible rather than crude units to express the SAA requirements of rabbits.

ACKNOWLEDGMENTS

Financial support was provided by CDTI-Eureka Program EU-619 'Rabbit Feed'. The authors are also grateful to COGAL SCL for allowing the use of its facilities for the slaughter of the animals.

REFERENCES

Adamson I, Fisher H (1973)Amino acid requirements of the growing rabbit: an estimate of quantitative needs. *J Nutr* 103, 1306-1310

AOAC (1984) *Official Methods of Analysis* (14th ed). Association of Official Analytical Chemists, Arlington, VA, USA

Berchiche M, Lebas F (1994) Supplémentation en méthionine d'un aliment à base de féverole: effets sur la croissance, le rendement à l'abattage et la composition de la carcasse chez le lapin. *World Rabbit Sci* 2, 135-140

Berchiche M, Lebas F, Ouhayoun J (1995) Utilisation of field beans by growing rabbits. 1. Effects of supplementations aimed at improving the sulphur amino acid supply. *World Rabbit Sci* 3, 35-40

Cheeke PR (1971) Arginine, lysine and methionine needs of the growing rabbit. *Nutr Rep Int* 3, 123-128

Cohen SA, Meys M, Tarvin TL (1989) *The pico.tag method. A manual of advanced techniques for amino acid analysis.* Millipore Corp, Bedford, USA

Colin M (1975) Effets sur la croissance du lapin de la supplémentation en L-lysine et en DL-méthionine de régimes végétaux simplifiés. *Ann Zootech* 24, 465-474

Colin M (1978) Effets d'une supplémentation en méthionine ou en cystine de régimes carencés en acides aminés soufrés sur les performances de croissance du lapin. *Ann Zootech* 27, 9-16

Colin M, Allain D (1978) Étude du besoin en lysine du lapin en croissance en relation avec la concentration énergétique de l'aliment. *Ann Zootech* 27, 17-31

Lebas F (1990) Recherche et alimentation des lapins. *Cuniculture* 17, 12-15

Longstaff M, McNab JM (1986) Influence of site and variety on starch, hemicellulose and cellulose composition of wheats and their digestibilities by adult cockerels. *Br Poultry Sci* 27, 435-449

Moughan PJ, Schultze WH, Smith WC (1988) Amino acid requirements of the growing meat rabbit. 1. The amino acid composition of rabbit whole-body tissue–A theoretical estimate of ideal amino acid balance. *Anim Prod* 47, 297-301

Robertson JB, Van Soest PJ (1981) The detergent system of analysis and its application to human foods. In: *The Analysis of Dietary Fiber in Foods* (WPT James, O Theander, eds), Marcel Decker, New York, USA, 123-158

Schlolaut , Lange K, Paufler S (1981) Einfluss des Thiaminosaürengehalt im Futter des Alters und des Geburtasaulösung mi Oxitocin auf die Reproducktionsleistung des Kaninchen bei pospartaler Insemination. *Züchtungk* 53, 282-294

Spreadbury D (1978) A study of the protein and amino acid requirements of the growing New Zealand white rabbit with emphasis on lysine and the sulphur-containing amino acids. *Br J Nutr* 39, 601-603

Statistical Analytical Systems Institute (1985) *SAS User's Guide: Statistics.* SAS Institute, Cary, NC, USA

Taboada E, Méndez J, Mateos GG, de Blas JC (1994) The response of highly productive rabbits to dietary lysine content. *Livest Prod Sci* 40, 329-337

Van Soest PJ (1963) Use of detergents in the analysis of fibrous feeds. 2. A rapid method for the determination of fibre and lignin. *J Assoc Off Anal Chem* 46, 828-835