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The effect of feeding high levels of low-quality proteins to growing chickens

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1. Three growth trials were done using male broiler chicks. In the first two trials, groundnut meal was used, with and without supplementary methionine and lysine. In the third trial, soya-bean meal was used with and without supplementary methionine. Protein levels ranged in the first trial from 120 to 420 g/kg diet and in the third trial from 120 to 300 g/kg diet. Thus the assumed minimal amino acid requirements of the chick were supplied by high levels of low-quality dietary protein.

2. Diets based on cereals and groundnut meal did not support maximum live-weight gain or maximum efficiency of food utilization at any level of dietary protein. When the principal deficiencies of lysine and methionine were corrected, this protein mixture was capable of supporting the same growth rate as a control diet of cereals and herring meal.

3. Diets based on maize and soya-bean meal did not support quite the same growth rate as similar diets supplemented with methionine, even though the protein level in the unsupplemented diets was sufficient to meet the assumed methionine requirements.

4. These results are interpreted as examples of amino acid imbalance in diets composed of familiar feeding-stuffs. It is concluded that one cannot assume that the poor quality of a protein source can always be offset by increasing the concentration of dietary protein.

Many reports deal with the problem of defining and measuring protein quality (e.g. Porter & Rolls, 1973) but less has been written about the incorporation of low-quality proteins into diets which satisfy the requirements for rapid growth. All measures of protein quality seek, directly or indirectly, to provide an index of the rate at which an animal synthesizes protein when given a diet with a specified (and limiting) concentration of protein. Such tests do not answer the important questions: (1) is it possible to achieve the maximum rate of protein synthesis of which the animal is capable merely by increasing the concentration of test protein in the diet; (2) if so, what concentration of dietary protein is needed to support maximum protein synthesis? In principle, slope-ratio assays, which form the basis of most protein-quality tests, are capable of predicting the answer to the second question, but only if (*a*) rectilinear responses are assumed to continue up to maximum performance, (*b*) the level of maximum performance is known, (*c*) the actual slopes (as distinct from the relative slopes) are reported.

Carpenter & de Muelenaere (1965) discussed these problems and reported evidence suggesting that chicks given a diet with a high level of protein supplied by groundnut flour (with supplementary lysine) grew as well as chicks given either a balanced diet or a lower level of groundnut protein supplemented with methionine as well as lysine. They did not report whether normal growth could be obtained from a high-protein groundnut diet without lysine supplementation. Subsequent papers by Carpenter & Anantharaman (1968) and Anantharaman, Carpenter & Nesheim (1968), although dealing with the value of poor-quality proteins given at high levels, were more concerned with the efficiency of protein utilization and the invalidity of the equations of Miller & Payne (1963) than with the direct question whether high levels of poor-quality proteins can support normal growth.

Negassi & Morris (1973) reported that a diet containing a high level of niger oilseed meal did not satisfy the chick's requirement for rapid growth, although excellent growth was obtained when the same diet, or a lower-protein diet, was supplemented with the first and second limiting amino acids. This was an instance in which amino acid imbalance prevented maximum output being obtained from a diet formulated on the basis that it was the cheapest and most suitable practical diet for feeding to young chicks in Ethiopia.

There seems to be no corresponding evidence to indicate whether maximum growth rate can be obtained using high levels of groundnut meal, without lysine or methionine supplementation, or high levels of soya-bean meal without methionine supplementation. Since these two protein sources are important in the total world economy, it is worth seeking better evidence about this aspect of their use in diets designed for animal or human feeding. This paper reports experiments in which high levels of groundnut or soya-bean meals were fed to growing chicks.

EXPERIMENTAL

Animals and facilities

Three experiments were done using fast-growing male chicks (Ross I; Ross Poultry Ltd, Rose Lane, Norwich NR1 1PU). The birds were housed at 1 d of age in four electrically-heated tiered brooders. Each brooder had eight compartments arranged on four levels, and sixteen or seventeen chicks were allocated to each compartment. Food and water were provided *ad lib.* Chicks and food were weighed at weekly intervals and the mean weights of groups were used to estimate treatment responses and error variances.

Plan of experiments

Expt 1. The first experiment was designed to compare responses to increasing concentrations of protein in diets using herring meal or groundnut meal or groundnut meal with supplementary methionine and lysine as the principal sources of protein ('H', 'G' and 'Glm' series of diets respectively). Cereals were used as the basis of the diets, since this imitates the situation in which the high-protein materials would normally be used, but the principal diets were designed so that the protein composition did not vary as dietary protein level was varied. Details of treatments are given in Table 1 and details of dietary composition are given in Table 2.

It was calculated from the values listed in Table 3 that, using groundnut meal, wheat and barley as the protein sources, a protein level of 360 g/kg (diet G36) would meet all the amino acid requirements of the chick (as given by Hewitt & Lewis (1972)) except for methionine which would be slightly below requirement. Diet G42 was included to allow for uncertainties in the tabulated requirements and foodstuff composition values. By adding synthetic methionine and lysine to the groundnut diets the

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Table 1. *Protein sources and treatments given to chicks in Expts 1 and 2*

Dietary protein level (g/kg)	Protein sources: Cereal–groundnut meal (G)	Cereal–groundnut meal plus lysine and methionine (Glm)		Cereal–herring meal (H)	
	Expt 1	Expt 1	Expt 2	Expt 1	Expt 2
120	G12	Glm12	—	H12	—
150	—	—	—	—	H15
180	G18	Glm18	Glm18	H18	H18
210	—	—	Glm21	H21	H21
240	G24	Glm24	Glm24	H24	H24
270	—	Glm27	Glm27	—	—
300	G30	—	—	—	—
360	G36	—	—	—	—
420	G42	Glm42	—	H42	—

requirements of the chick could be met at 240 g protein/kg (diet Glm24). Diet Glm27 was introduced to allow a margin for uncertainty and diet Glm42 was included to test whether the very high level of groundnut meal included in diet G42 (790 g/kg) was itself toxic. The groundnut meal used in the experiment was analysed for aflatoxin content by courtesy of BOCM-Silcock Ltd, Basing View, Basingstoke, Hants, and was reported to contain less than 0·5 mg/kg. Using herring meal as the protein supplement, the chick's estimated requirements could be satisfied by 210 g protein/kg (diet H21). Diet H24 was included to allow a margin for uncertainty and diet H42 was added to check that a high dietary protein level was not necessarily incompatible with rapid growth.

Diet G36 was formulated first. The composition of diet G12 was then obtained by adding maize oil, maize starch, glucose and oat hulls at the expense of cereals and groundnut meal to provide an isoenergetic diet containing 120 g protein/kg. Cereals and groundnut meal were displaced in equal proportions so that the amino acid composition of the protein remained the same throughout the 'G' series of diets. Large batches of diets G12 and G36 were prepared and diets G18, G24 and G30 were obtained by blending the appropriate proportions of diets G12 and G36 together. Diet G42 was formulated by increasing groundnut meal at the expense of cereals and so did not have the same amino acid composition as the other groundnut diets. Diets Glm12, Glm18, Glm21, Glm24 and Glm27 were obtained by blending together appropriate amounts of G12 and G36 and adding L-lysine HCl and DL-methionine. The levels of the third and fourth limiting amino acids (threonine and cystine) in diet Glm27 were estimated to be 1·25 times the chick's requirement and it was calculated that the addition of 2·32 g methionine and 2·18 g lysine HCl/kg diet would bring the levels of these amino acids to 1·25 times requirement also. Amino acid additions to the other diets in the 'Glm' series were in corresponding proportion to their protein contents.

Diet H12 was formulated by diluting diet H24 (see Table 2) and diets H18 and H21 were made by blending diets H12 and H24 together. The high-protein control diet

Table 2. *Composition (g/kg) and calculated analysis of principal diets containing cereals and groundnut meal (G), herring meal (H) or soya-bean meal (S) as principal protein sources given to chicks in Expts 1 and 3*

	Expt 1						Expt 3		
Diet*...	G12	G36	G42	H12	H24	H42	S12	S30	
Ingredients									
Ground wheat	50	150	72	192	384	49	—	—	
Ground barley	50	150	72	192	384	—	—	—	
Ground maize	—	—	—	—	—	49	112·4	281	
Groundnut meal	213	638	790	—	—	—	—	—	
Herring meal	—	—	—	104	208	170	—	—	
Extracted soya-bean meal	—	—	—	—	—	650	249·6	624	
Glucose	400	—	—	305	—	—	350	—	
Maize starch	160	—	—	100	—	—	150	—	
Ground oat hulls	79	—	—	68·3	—	—	72·5	—	
Maize oil	10	35·5	39·5	10	10	69	26	62	
Limestone flour	4·9	—	—	8·7	9·4	8·0	7·2	9·0	
Dicalcium phosphate	25·5	20·8	20·4	13·3	—	—	24·4	17·0	
Sodium chloride	4·3	3·6	3·6	3·1	1·6	2·6	4·4	4·0	
Vitamin–mineral mix†	3·3	2·1	2·5	3·6	3·0	2·4	3·5	3·0	
Calculated analysis									Requirement§
Metabolizable energy (kJ/kg)	12·2	12·2	12·2	12·2	12·2	12·2	12·3	12·3	
Crude protein (nitrogen × 6·25) (g/kg)	120	360	420	120	240	420	120	300	
Ca (g/kg)	10·1	10·0	10·9	10·1	10·1	10·2	10·0	10·0	
Phosphorus (g/kg)	5·0	5·1	5·1	5·2	5·6	5·7	5·2	5·2	
Methionine (g/kg)	1·2	3·7	4·2	2·7	5·4	7·8	1·8	4·6	4·0
Methionine + cystine (g/kg)	3·1	9·4	10·8	4·7	9·4	14·3	3·7	9·3	7·5
Lysine (g/kg)	4·2	12·6	14·8	8·1	16·2	30·0	7·5	18·7	9·0
Tryptophan (g/kg)	1·2	3·6	4·1	1·4	2·8	5·5	1·6	4·0	1·7
Isoleucine (g/kg)	5·1	15·3	18·0	4·0	8·0	23·0	6·7	16·7	7·0
Valine (g/kg)	5·2	15·6	18·1	5·6	11·2	21·3	6·2	15·5	8·0
Threonine (g/kg)	3·3	10·0	11·6	4·3	8·6	16·8	4·9	12·3	6·0
Leucine (g/kg)	7·6	22·8	26·4	8·1	16·2	30·9	9·5	23·7	12·0
Arginine (g/kg)	11·6	34·6	41·8	9·0	18·0	34·1	9·0	22·6	8·5
Histidine (g/kg)	2·6	7·8	9·0	2·6	5·2	10·1	3·0	7·5	4·0
Phenylalanine (g/kg)	5·6	16·8	19·7	5·1	10·2	22·5	7·1	17·7	7·0
Phenylalanine + tyrosine (g/kg)	9·4	28·2	32·8	8·7	17·4	33·1	10·0	24·9	13·0
Glycine (g/kg)	6·0	18·0	21·2	8·0	16·0	24·2	5·8	14·5	6·0
Chemical score‡	30	92	105	57	114	190	45	115	
First limiting amino acid	Methionine	Methionine	Methionine	Isoleucine	Isoleucine	Methionine + cystine	Methionine	Methionine	

* For details of dietary protein levels and treatments for Expt 1, see Table 1 and for Expt 3, see p. 367.

† 1 kg vitamin–mineral mix supplied: 0·78 g retinol, 15 mg cholecalciferol, 1·8 g riboflavin, 2·2 mg cyanocobalamin, 1·48 g α-tocopherol, 0·9 g menaphthone, 3·5 g pantothenic acid, 6·6 g nicotinic acid, 0·4 g folic acid, 110 g choline, 2·2 g copper, 33·1 g manganese, 0·4 g iodine, 22·1 g zinc.

‡ The chemical score given is the amount of the first limiting amino acid in each diet expressed as a percentage of the requirement according to Hewitt & Lewis (1972).

§ Selected values from Hewitt & Lewis (1972).

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Table 3. *Assumed metabolizable energy (kJ/kg) and crude protein and amino acid contents (g/kg) of the protein sources used in diets given to chicks*

	Ground maize	Ground wheat	Ground barley	Groundnut meal	Herring meal	Soya-bean meal
Metabolizable energy	14·4	12·9	11·4	11·5	12·6	9·6
Crude protein (nitrogen × 6·25)	90	120	110	510	720	440
Methionine	1·8	1·7	1·6	5·0	20·0	6·5
Methionine + cystine	3·6	3·7	3·6	13·0	32·0	13·2
Lysine	2·0	3·5	4·0	18·0	64·0	29·0
Tryptophan	1·0	1·0	1·5	5·0	9·0	6·0
Isoleucine	4·0	5·0	4·0	22·0	37·0	25·0
Valine	4·0	5·0	5·2	22·0	35·0	23·0
Threonine	3·7	3·6	3·5	14·0	28·0	18·0
Leucine	11·0	8·0	7·0	32·0	50·0	33·0
Arginine	4·3	4·8	5·0	52·0	68·0	34·0
Histidine	2·3	2·4	2·3	11·0	16·0	11·0
Phenylalanine	5·0	5·0	5·5	24·0	30·0	26·0
Phenylalanine + tyrosine	8·2	9·0	8·5	40·0	52·0	36·0
Glycine	5·0	6·0	3·5	26·0	59·0	21·0

(H42) was prepared by using the maximum amount of herring meal, without exceeding an upper limit for phosphorus, and then adding soya-bean meal to make up the protein; the proportion of herring meal in diet H42 was less than that in diet H24.

Two groups, each of sixteen or seventeen chicks, were allocated in a randomized block design to each of the sixteen diets at 7 d of age. Experimental diets were given from 7 to 21 d of age. From 1 to 7 d of age all chicks were fed on a diet containing 200 g groundnut meal and 54 g herring meal/kg diet and calculated to contain 220 g protein/kg.

Expt 2. This was a trial designed to clear up some doubts which were left by Expt 1. Eight diets were used with four groups, each of sixteen or seventeen chicks, allocated to each diet. Treatments were arranged at random in four blocks, with each brooder forming one block, but with the added constraint that each treatment appeared only once in each tier.

The treatments were four levels of protein supplied by cereals, groundnut meal and supplementary methionine and lysine, and four levels of protein supplied by cereals and herring meal (see Table 1). Diets were prepared in the same way as the 'Glm' series and the 'H' series in Expt 1 (see Table 2). The same sample of groundnut meal was used but other foodstuffs were drawn from fresh consignments.

The same 'starter' diet was used as in Expt 1 and the treatments were given from 7 to 28 d of age.

Expt 3. In this trial soya-bean meal was tested with and without methionine supplementation ('S' and 'Sm' series of diets respectively). Maize was used as the cereal base because it is the common cereal in areas where soya beans are grown for oil extraction. A high-protein diet was formulated (S30 in Table 2) and five lower protein levels (270, 240, 210, 180 and 120 g protein/kg) were obtained by dilution with protein-free materials. The composition of the lowest-protein diet (S12) is given in Table 2 and those of intermediate diets can be deduced by linear interpolation. A

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Table 4. *Expt* 1. *Mean live weights and food consumption of chicks given, from 7 to 21 d of age, diets containing cereals and groundnut meal (G), groundnut meal with supplementary methionine and lysine (Glm) or herring meal (H) as the principal sources of protein*

Diet*	Mean live wt (g) 14 d	21 d	Mean food intake (g/chick) (7–21 d)	Food conversion efficiency (g wt gain/g food intake) (7–21 d)	Net protein intake† (g) (7–21 d)
G12	104	130	245	0·204	8·8
G18	127	190	345	0·316	27·9
G24	146	258	401	0·445	58·7
G30	165	308	446	0·506	101·7
G36	180	354	458	0·594	151·7
G42	169	335	459	0·553	202·4
Glm12	120	167	318	0·275	21·0
Glm18	152	272	455	0·423	67·2
Glm24	180	352	499	0·552	131·8
Glm27	182	373	488	0·597	164·7
Glm42	196	381	475	0·643	379·1
H12	167	293	494	0·421	33·8
H18	190	359	531	0·525	81·3
H21	211	412	538	0·611	113·0
H24	195	362	491	0·570	134·3
H42	210	403	501	0·648	401·9
SE of means	3·6	8·5	12·3	0·0114	

Over-all mean live wt at 7 d was 80 g.

* Two groups, each of sixteen or seventeen chicks, received each diet; for details of diets, see Tables 1 and 2.

† (Total protein intake × chemical score (as given in Table 3)) ÷ 100.

second series of diets (Sm12–Sm30) was obtained by adding DL-methionine at levels calculated to provide a total of 0·4 g methionine/22 g protein (i.e. an addition of 0·34 g methionine/kg diet to S12 and 0·85 g methionine/kg diet to S30).

Each diet was given from 1 to 21 d of age to two groups, each of sixteen or seventeen chicks, using a randomized block design.

RESULTS

The chicks grew well in all three experiments. Mortality rates during the course of the treatments were 0·8, 2·3 and 1·2 % in Expts 1, 2 and 3 respectively.

Tables 4, 5 and 6 summarize values for mean live weights, food intake and efficiency of food utilization for the three experiments. 'Net protein' intakes (g protein intake/chick × chemical score ÷ 100) are also given in these tables as indices of the relative intakes of the first limiting amino acid on the different diets. Fig. 1 summarizes the principal responses of live-weight gain to dietary protein level.

Expt 1

The protein sources ranked in the expected order, with marked differences between them in both growth rate and food conversion efficiency when protein was limiting. In the 'G' series of diets, growth improved as protein level was increased up to

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360 g/kg. However, the maximum 21 d live weight obtained with unsupplemented groundnut protein was only 86 % of the maximum reached by chicks given a lower level of protein from cereals and herring meal.

Supplementation of the groundnut meal with methionine and lysine resulted in substantial improvements in growth rate. At the two lowest protein levels 'Glm' diets did not support the same growth as the 'H' series, but it was not expected that they would because the amino acid compositions of the two series of diets were not equivalent. By increasing the dietary protein level in the 'Glm' series to 270 g/kg a performance almost equal to that with diet H21 was obtained. The difference in 21 d live-weight values between diets H21 and Glm27 was significant ($P < 0.05$) but the difference in efficiency of food utilization was not.

At 420 g protein/kg both the herring meal and the supplemented groundnut diets gave good growth and excellent food conversion efficiency. Thus the failure of the unsupplemented groundnut diets to support maximum growth at any level of protein cannot be attributed to toxicity or to simple unpalatability of the groundnut meal, or to inability of the chick to deal with diets containing high levels of protein. The intakes of methionine for diets G36 and G42 were very substantially greater than that for diet H21 and therefore poor growth with the groundnut diets cannot be attributed to simple deficiency of the first limiting amino acid. The presumption must be that the failure of the groundnut diets was due to the unfavourable balance of amino acids in the protein, as the simple addition of lysine and methionine restored performance almost to the maximum level.

Because the H21 diet supported a growth rate which was significantly better than H24 and Glm24 and Glm27, but did not show a significantly better food conversion efficiency, it was thought advisable to repeat parts of the 'H' and 'Glm' series, with additional replication (Expt 2).

Expt 2

The chicks used for this experiment were heavier when delivered from the hatchery and at 7 d of age they weighed 30 % more than those of Expt 1. Growth rates were therefore better throughout the trial but the pattern of responses was similar to that obtained with corresponding diets in Expt 1. Live weights were the same with diets H21 and H24 and the same live weight was obtained with diet Glm27, but food intake was significantly higher.

In Expt 1 food intake at all levels of protein had been higher for the 'H' series of diets than for the 'Glm' series but in Expt 2 the chicks ate more of the high-protein groundnut diets than of the high-protein herring diets. This may account for the better growth rates with the 'Glm' series of diets in Expt 2.

We may conclude that a diet based on cereals and groundnut meal and incorporating supplementary methionine and lysine is capable of supporting maximum growth rate in the baby chick, although the level of protein required will of course be greater than that needed when a high-quality protein is used.

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Table 5. *Expt 2. Mean live weights and food consumption of chicks given, from 7 to 28 d of age, diets containing cereals and increasing amounts of groundnut meal with supplementary methionine and lysine (Glm) or herring meal (H) as the principal sources of protein*

Diet*	Mean live wt (g)			Mean food intake (g/chick) (7–28 d)	Food conversion efficiency (g wt gain/g food intake) (7–28 d)	Net protein intake† (g) (7–28 d)
	14 d	21 d	28 d			
Glm18	209	358	561	1051	0·428	155·1
Glm21	222	392	628	1111	0·465	224·0
Glm24	242	448	722	1200	0·510	316·8
Glm27	258	498	803	1216	0·568	410·4
H12	238	433	671	1209	0·463	128·8
H18	253	466	737	1153	0·543	176·4
H21	262	502	791	1152	0·591	241·9
H24	258	501	800	1148	0·602	314·1
SE of means	4·8	6·1	9·7	17·8	0·0100	

Over-all mean live wt at 7 d was 111 g.

* Four groups, each of sixteen or seventeen chicks, received each diet; for details of diets, see Tables 1 and 2.

† (Total protein intake × chemical score (as given in Table 3)) ÷ 100.

Table 6. *Expt 3. Mean live weights and food consumption of chicks given, from 1 to 21 d of age, diets containing increasing amounts of cereal and soya-bean meal (S) or soya-bean meal with supplementary methionine (Sm) as the principal sources of protein*

Diet*	Mean live wt (g)			Mean food intake (g/chick) (0–21 d)	Food conversion efficiency (g wt gain/g food intake) (0–21 d)	Net protein intake† (g) (0–21 d)
	7 d	14 d	21 d			
S12	95	178	257	594	0·369	32·1
S18	115	253	435	752	0·528	92·1
S21	121	274	492	754	0·603	126·6
S24	119	280	511	740	0·640	163·4
S27	118	275	506	706	0·663	196·3
S30	116	261	467	701	0·612	241·8
Sm12	103	212	340	712	0·425	47·0
Sm18	117	269	471	776	0·558	114·6
Sm21	127	292	531	806	0·612	160·8
Sm24	130	300	539	783	0·640	202·9
Sm27	122	281	512	698	0·680	230·0
Sm30	116	264	473	646	0·674	261·6
SE of means	2·6	6·5	12·4	18·5	0·0133	

* Two groups, each of sixteen or seventeen chicks, received each diet; for details of diets, see p. 367 and Table 2.

† (Total protein intake × chemical score (as given in Table 3)) ÷ 100.

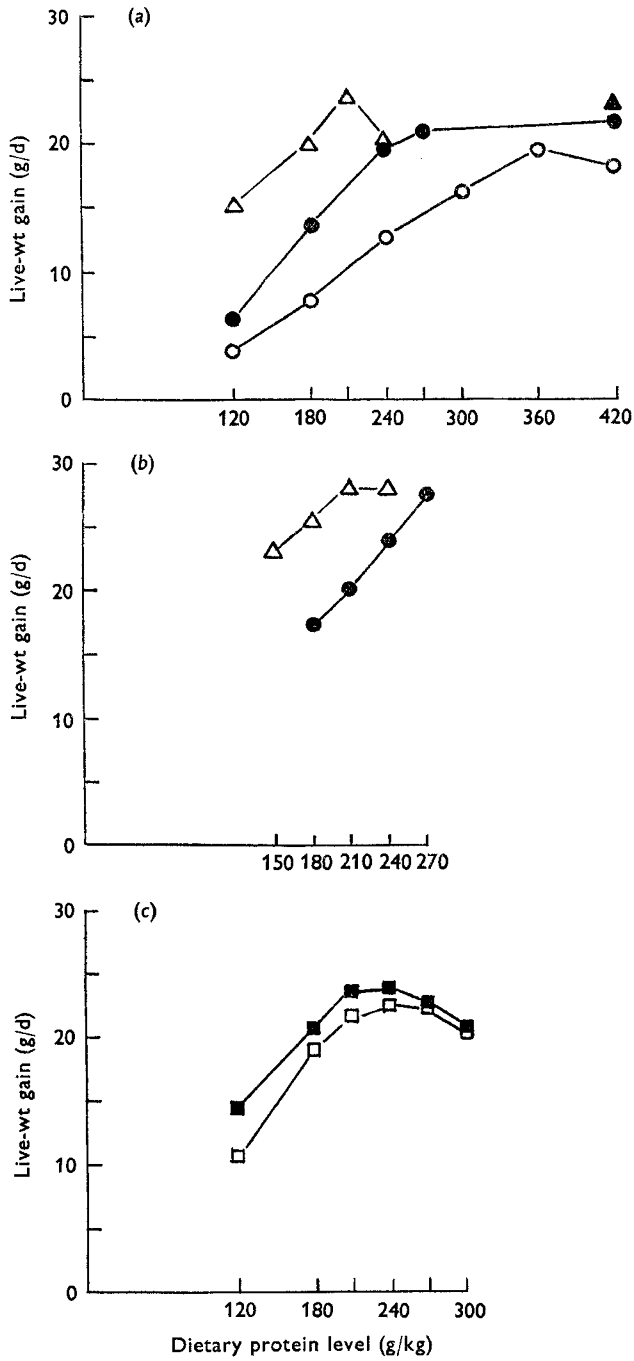

Fig. 1. Growth responses in the three experiments: (*a*) Expt 1, (*b*) Expt 2, (*c*) Expt 3, in which groups of chicks were given diets containing cereals and increasing amounts of (△——△), herring meal; (▲), herring meal and soya-bean meal; (○——○), groundnut meal; (●——●), groundnut meal plus methionine and lysine; (□——□), soya-bean meal; (■——■), soya-bean meal plus methionine, as the principal sources of protein, from 7 to 21 d of age (Expt 1), 7 to 28 d of age (Expt 2) or 0 to 21 d of age (Expt 3). For details of diets and treatments, see Tables 1 and 2 and p. 365.

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Expt 3

The chicks used for Expt 3 were not particularly large (39 g at 1 d of age) but their growth rate was excellent (Table 6). The addition of methionine to the maize–soya-bean diets gave a growth response at all levels of dietary protein (Fig. 1). The difference between diets S24 and Sm24, considered in isolation, was not quite significant but the pattern of responses was consistent and the mean weight of chicks given diets Sm21 and Sm24 was about 6% greater than the mean weight of chicks given diets S21 and S24; this difference was statistically significant ($P < 0.05$). At the four lower protein levels, food intake was less with the 'S' series of diets than with the 'Sm' series of diets and good food conversion efficiencies were obtained with diets S21, S24 and S27. In terms of efficiency of food utilization, the unsupplemented diets given at high levels of protein were as good as the supplemented diets.

DISCUSSION

Groundnut meal and soya-bean meal are two commonly used sources of protein and it is well known that, for growing animals, soya-bean meal is deficient in methionine, and groundnut meal is deficient in both lysine and methionine. These deficiencies are not remedied by mixing the materials with cereals.

In the experiments reported here, maximum growth rate could not be obtained when groundnut meal or soya-bean meal was used as a simple supplement to a cereal-based diet, even though very high dietary protein levels were used. This failure to support maximum live-weight gain might be attributed to: (*a*) poor palatability; (*b*) a toxin or anti-nutritive factor present in the feedstuff; (*c*) a toxic effect of high protein levels; (*d*) an amino acid deficiency; or (*e*) amino acid imbalance, that is, an interference with the utilization of the first limiting amino acid(s) due to the excessive levels of other amino acids. The possibility that the high-protein groundnut and soya-bean diets gave poor results because they were unpalatable or toxic was removed by the finding that supplementation with the first (and, if necessary, second) limiting amino acid(s) improved growth rate at those high dietary protein levels. Deficiency of the first limiting amino acid was possible, but very unlikely. If the G42 diet contained less than the calculated 4·2 g methionine/kg, or if the chick's requirement is more than 4·0 g/kg, methionine intake might have been 'deficient'. But if that were the proper explanation one would expect continuing responses to increasing levels of groundnut meal, whereas both growth and food conversion efficiency were lower for diet G42 than for diet G36. Similar arguments apply to the high-protein soya-bean diets.

The only explanation which fits the evidence is that the amino acids supplied by these low-quality proteins are in such disproportion, compared with the animal's needs, that the utilization of the first limiting amino acid(s) is impaired. These results will not be surprising to those who have studied amino acid imbalance using purified diets (for review, see Harper, Benevenga & Wohlhueter (1970)) but it has perhaps not been sufficiently appreciated that imbalance can occur in diets formulated from familiar foodstuffs.

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It should be noted that, although maximum growth rate is an important objective for a food compounder selling broiler diets in a competitive economy, it may not be an important criterion for poultry production in other parts of the world. Where groundnut meal or soya-bean meal is available and high-quality proteins and synthetic amino acids are expensive or unavailable, reasonable growth rates can be attained with all-vegetable diets. Also, compensatory growth may occur so that differences due to the type of protein supplied may not be apparent at later ages. Whether similar arguments can properly be applied to human nutrition, or whether early protein malnutrition has irreparable effects on human development, is a matter of some importance, but one that cannot be answered by experiments with chicks.

The implication of these results for those concerned with the assessment of protein quality are serious. Protein quality measurements such as gross protein value (Anwar, 1960), net protein utilization (Summers & Fisher, 1961) or total protein efficiency (Woodham, 1968) place proteins in a rank order with respect to their ability to support growth when given in limiting quantities, but they do not indicate whether the materials are capable of supporting maximum growth or at what level they should be fed to achieve this. It is noticeable that the responses shown in Fig. 1 are mostly converging as dietary protein level is increased and not diverging as would be expected of a slope-ratio assay. This means that three-point assays of the type commonly employed to compare the relative qualities of two proteins will give false predictions about the amounts of the lower-quality protein which are needed to achieve maximum growth.

Finally, the most urgent question is how one can set rules for formulation which will ensure that diets with amino acid imbalance are not produced. D'Mello & Lewis (1970) have published estimates of the amounts of arginine needed to offset excesses of lysine and have studied the interrelationships between leucine, isoleucine and valine. None of these antagonisms would appear to be responsible for the effects reported in the experiments above. Some system is needed which sets upper as well as lower limits for each amino acid or which specifies appropriate ratios that must be maintained. It seems that much more experimental evidence will be needed before such a system can be defined.

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