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MUTUAL SUPPLEMENTATION OF DIETARY PROTEINS FOR MEETING PROTEIN NEEDS AND OVERCOMING PROTEIN SHORTAGE IN DEVELOPING COUNTRIES

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The primary function of dietary proteins is to provide amino acids in appropriate patterns for the synthesis of tissue proteins during growth, for the maintenance of established cellular nitrogenous constituents and for other metabolic needs. The nutritive value of a protein depends on its amino acid make-up. The pioneering investigations of Wilcock and Hopkins [1] Osborne and Mendel[2] and Rose and his collaborators[3] have established the essential nature of several amino acids. Rose and his co-workers[3] have shown that out of the 22 amino acids commonly occurring in food proteins, 10 are essential for the growth of albino rats in the sense that they must be provided by the dietary protein. The remaining 12 amino acids can be synthesised in the body and hence are called non-essential amino acids. Since non-essential amino acids can spare essential amino acids, they must also be present in the diet in adequate amounts[4]. The classification of the amino acids from the nutritional standpoint is given in Table I.

Table I. *Nutritive classification of the amino acids*

Essential (indispensable)	Semi indispensable	Non-essential (dispensable)
Histidine	Arginine*	Glutamic acid
Lysine	Tyrosine†	Aspartic acid
Tryptophan	Cystine†	Alanine
Phenylalanine	Glycine*	Proline
Methionine	Serine*	Hydroxyproline
Threonine		
Leucine		
Isoleucine		
Valine		

* Arginine and glycine are essential for chicks and turkeys. Serine will spare or replace glycine.

† Tyrosine will spare but not completely replace phenylalanine. Cystine will spare but not completely replace methionine.

Amino acid balance and imbalance: The complete absence of any one essential amino acid in a dietary protein produces negative nitrogen balance and does not promote growth, while partial deficit of any one essential amino acid lowers the growth promoting value of the protein.[5] The majority of plant proteins is partially deficient in one or more amino acids.[3,6] The proportions of other essential amino acids present in the proteins have also been found to affect the utilisation of the limiting amino acids. This is known as amino acid imbalance.[7] The results of amino acid imbalance studies indicate that even a small increase in the concentration of certain amino acids sometimes increases the amounts of others needed to maintain a given rate of growth when the total protein intake is low.[8] When a mixture of amino acids lacking in one essential amino acid is added to a diet, especially a low-protein diet, the total amino acid (protein) content of the diet is increased and more of the limiting acid (expressed as % of the diet) is required to prevent a depression in growth rate. The absolute amount of limiting amino acid required to overcome the depression may also be increased.[8,9] In experiments on protein mixtures prepared from a mixture of casein and gelatin in different proportions and having a wide range of 'chemical scores' (an index of amino acid deficiency) the rat tolerated a protein mixture with 'chemical score' of 50 without any apparent ill effects. If the 'chemical score' fell below 50, food intake and growth were depressed. Further work is needed on this aspect as the depressing effect on growth will depend on the degree of amino acid imbalance in the mixture.

The nutritive value of food proteins: The nutritive value of the proteins of common foods and protein supplements has been determined by a large number of workers. The results have been summarised by Block and Mitchell,[5] Kuppuswamy *et al*[6] and Patwardhan.[10] Some of the available data are given in Table II.

Cereals: Cereals contribute more than 50 percent of proteins in the diets of low-income groups in almost all developing countries and hence form the most important source of dietary protein.[11,12] They contain moderate amounts of protein varying from 6-14%, depending on the cereal. The limiting amino acids in most cereal proteins are lysine and threonine. Maize and sorghum proteins have also amino acid imbalance.[6,7] The protein efficiency ratios of the cereals and millets range widely from 0.5 to 2.4 depending on the grain and are given in Table II.

Legumes: Legumes are good sources of protein containing about 18-25%. About 15-30% of the total proteins in average diets consumed by the low-income groups in developing countries may be derived from legumes depending on the region.[11] Legume proteins are good sources of lysine and threonine but are limiting in sulphur amino acids and tryptophan.[6] Optimal heat processing has been shown to bring about an increase in the nutritive value of legumes by inactivating trypsin and growth inhibitors present in them.[13] The protein efficiency ratios of optimally heat processed legumes may range from 1.0 to 2.2 depending on the legume and are given in Table II.

Nuts and oilseeds: Nuts and oilseeds are, in general, good sources of proteins[6]. Oilseed meals form important potential sources of proteins for overcoming protein malnutrition in developing countries.[14] The most important of these are meals obtained from soyabean, groundnut, cottonseed, sesame, coconut and sunflower seeds. The protein efficiency ratios of nuts and oilseeds range from 1.5 to 2.5 depending on the material and are given in Table II.

Roots and tubers: Among the roots and tubers potato is a fair source of proteins when considered on moisture-free basis. The protein efficiency ratios of potato proteins vary widely and are given in Table II.

Egg and milk: The proteins of egg possess the highest nutritive value among dietary proteins.[6] Milk proteins possess high nutritive value though lower than that of egg proteins. The protein efficiency ratios of egg and milk proteins are given in Table II.

Meat and fish: The proteins of meat and fish possess high nutritive value comparable to those of milk proteins.[6] Data regarding the protein efficiency ratios of meat and fish proteins are given in Table II.

Food yeast: Food yeast proteins are rich sources of lysine and threonine but are deficient in sulphur amino acids.[6] Data regarding the protein efficiency ratio of food yeast proteins are given in Table II.

Supplementary relations between cereal proteins and other dietary proteins: Data available on the supplementary relations between cereal proteins and other dietary proteins are briefly summarised below.

Legumes: Since legume proteins are rich in lysine and threonine they supplement to a marked extent those of cereal proteins, which are in general limiting in these amino acids.[6] Cereal-legume mixtures contain proteins of superior nutritive value as compared with that of cereal or legume proteins.[15-18] The proteins of legumes such as Bengal gram (Chick pea), black gram, green gram and red gram (Pigeon pea) supplement the proteins of wheat, sorghum and pearl millet to a marked extent.[19]

Oilseed meals:

Soyabean meal: Being a rich source of lysine and threonine, soyabean proteins supplement to a marked extent those of wheat[20,21], yellow maize[21] and rye.[20]

Groundnut meal: Groundnut proteins supplement to a significant extent those of wheat proteins,[22] though inferior in this respect to the proteins of soyabean and milk. Groundnut proteins have also been reported to supplement to a significant extent the proteins of oats[23], corn[21] and rice.[24]

Cottonseed meal: Cottonseed proteins have been reported to supplement to a

Table II. *The protein efficiency ratios of some common food proteins*

Foodstuff	Botanical Name	Level of protein in diet %	Duration of experiment (days)	PER	Reference No.
I	II	III	IV	V	VI
Cereals and millets					
Rice, husked	*Oryza sativa*	10	28	2.0	19
Rice, milled	*Oryza sativa*	5	70	1.9	55
,, ,,	*Oryza sativa*	6	70	1.8	56
Wheat, whole	*Triticum vulgare*	5	70	0.9	57
,, ,,	*Triticum vulgare*	9	70	1.1	57
Wheat, whole, hard spring	*Triticum vulgare*	5	42	1.7	58
,, ,, ,, ,,	*Triticum vulgare*	10	42	1.6	58
Wheat germ	*Triticum vulgare*	10	42	2.5	59
Buckwheat, whole groats	*Fagopyrum esculentum*	8	30	2.5	60
,, ,,	*Fagopyrum esculentum*	13	30	2.1	60
Kaffir corn	*Sorghum vulgare*	5	28	0.9	61
Kaffir corn	*Sorghum vulgare*	8	56	1.2	31
Kaffir corn	*Sorghum vulgare*	10	28	2.0	19
Oats, rolled	*Avena sterilis*	5	42	2.2	58
Oats, rolled	*Avena sterilis*	10	42	2.5	58
Pearl millet	*Pennisetum typhoideum*	5	28	1.3	61
Pearl millet	*Pennisetum typhoideum*	10	56	1.4	62
Pearl millet	*Pennisetum typhoideum*	10	28	1.8	19
Ragi	*Eleucine coracana*	5	28	1.0	61
Barley, pearled	*Hordeum vulgare*	5	42	1.6	58
Barley, meal	*Hordeum vulgare*	9	30	2.0	50
Rye, whole	*Secale cereale*	5	42	2.3	58
Rye, whole	*Secale cereale*	8	42	2.2	58
Rye, whole	*Secale cereale*	10	42	1.8	58
Italian millet	*Setaria italica*	10	28	0.8	79
Little millet	*Panicum miliare*	10	28	1.1	79
Corn, whole, white	*Zea mays*	9	63	1.3	63
Corn, whole, yellow	*Zea mays*	5	70	0.5	57
Corn, whole, yellow	*Zea mays*	7	70	0.9	57
Corn, whole, yellow	*Zea mays*	8	42	1.2	64
Legumes					
Bengal gram, cooked	*Cicer arietinum*	10	10	1.8	65
Black gram, autoclaved	*Phaseolus mungo*	12	40	1.6	66
Green gram, cooked	*Phaseolus aureus*	10	28	1.5	19
Horse gram, autoclaved	*Dolichos biflorus*	12	37	1.7	66
Red gram, cooked	*Cajanus cajan*	10	28	1.7	19
Lathyrus pea, autoclaved	*Lathyrus sativus*	12	21	0.4	67
Kidney bean, cooked	*Phaseolus vulgaris*	10	30	1.5	15
Lima bean, autoclaved	*Phaseolus lunatus*	10	56	1.2	68
Lentil, cooked	*Lens culinaris*	10	30	1.2	15
Pea, cooked	*Pisum sativum*	10	56	1.0	69
Pea, raw (Alaska)	*Pisum sativum*	10	42	1.3	18
Roots and tubers					
'Great Scot' potato, cooked		8.5	56	1.2	70
'Great Scot' potato flour		8.5	56	1.2	70
'Up-to-date' potato, cooked		6.5	56	1.0	70
'President' potato, cooked		6.5	56	2.0	70
'Up-to-date' potato flour		6.5	56	1.0	70
Nuts and oilseeds					
Groundnut meal (Expeller pressed)		10	28	1.7	41
Cottonseed meal (Expeller pressed)		9	42	2.1	22
Cottonseed meal, cooked		10	42	2.0	71

I	II	III	IV	V	VI
Soyabean, raw		10	28	0.5	72
Soyabean, heat processed		10	28	2.4	72
Sesame flour		10	28	1.7	41
Sunflower meal		10	28	2.6	41
Safflower seed cake		10	56	1.3	73
Coconut meal		10	28	2.0	42
Egg and milk					
Egg, hen		10	28	4.7	74
Milk, cow		10	28	3.3	74
Milk, buffalo		10	28	3.4	75
Milk, goat		10	28	2.9	75
Meat and fish					
Beef		10	30	3.2	76
Pork		10	30	3.4	76
Chicken		8	42	3.6	77
Fish flour (from oil sardine)		10	28	2.9	51
Yeast and chlorella					
Food yeast	*Torula utilis*	8	56	1.8	31
Chlorella		10	28	2.2	78

significant extent those of wheat[22] and corn.[25]

Sesame meal: Jaffe[26,27] conducted a series of rat feeding trials for the biological evaluation of sesame meal alone and in various combinations with corn meal and groundnut meal. On the basis of encouraging results of the rat feeding tests, *arepas* (local corn breads) were prepared with varying amounts of toasted sesame seed.

Coconut meal: The proteins of coconut have been found to supplement to a marked extent those of rice[28] and maize.[29]

Leaf proteins: Phansalkar *et al*[19] have reported that amaranth leaf proteins supplement those of cereal and legume proteins. Lucerne proteins supplement the proteins of rice[29a] and of whole yellow corn.[29b]

Food yeast: The proteins of food yeast supplement to a significant extent those of wheat,[30] corn,[30] oats,[30] sorghum[31] and ragi.[31]

Milk: Milk proteins supplement to a highly significant extent those of rice,[32] corn,[33] wheat[33] and ragi.[34]

Meat: Meat proteins have been found to supplement cereal proteins to a highly significant extent.[35-37]

Fish: Fish proteins even when incorporated at a low level supplement to a marked extent those of different cereals.[38,39]

Supplementary relations between certain oilseed meals and legumes: The proteins of sesame and sunflower seeds are rich in methionine and tryptophan while those of legumes are partially deficient in these amino acids. Sesame proteins supplement to a marked extent those of soya bean,[40] groundnut[41] and Bengal gram.[41] The proteins of sunflower seeds supplement to a significant extent those of groundnut[41] and Bengal gram.[41] Coconut proteins have been found to supplement to a significant extent those of Bengal gram[42] and groundnut proteins.[42]

Supplementary value of protein-rich foods to deficient diets based on cereals, roots and tubers: A large amount of work has been carried out during recent years on the supplementary value of protein-rich foods and processed protein foods based on blends of protein-rich foods to poor quality diets based on different cereals, roots and tubers.[43-50] Data regarding the amino acid composition and protein efficiency ratio are given in Table IV and the supplementary value of the protein blends to poor diets based on different cereals in Table V. A brief summary of the available data is given below.

Groundnut flour and protein foods based on groundnut flour: The supplementary value of low-fat groundnut flour fortified with calcium salts and vitamins A and D and 4 : 1 blend of fortified groundnut flour and skim milk powder to deficient diets based on rice or 1 : 2 blend of maize and tapioca flours has been studied by Tasker

Table III. *Supplementary relations between different dietary proteins*

Basic protein source	Supplementary protein source	Quantity of total protein in diet provided by supplementary food (%)	Protein content in diet (%)	PER	Reference No.
I	II	III	IV	V	VI
Cereals and millets					
Barley	Pea	50	10	1.98	18
Italian millet	Cereal alone	—	10	0 80	79
Italian millet	Bengal gram and amaranth leaf	40	10	2.20	79
Kaffir corn	Cereal alone	—	10	1.61	19
Kaffir corn	Bengal gram	30	10	1.89	19
Kaffir corn	Black gram	30	10	1.96	19
Kaffir corn	Green gram	30	10	1.80	19
Kaffir corn	Red gram	30	10	1.84	19
Kaffir corn	Amaranth leaf	10	10	1.70	19
Kaffir corn	Bengal gram and amaranth leaf	40	10	1.89	19
Kaffir corn	Black gram and amaranth leaf	40	10	1.77	19
Kaffir corn	Green gram and amaranth leaf	40	10	1.72	19
Kaffir corn	Red gram and amaranth leaf	40	10	1.85	19
Little millet	Cereal alone	—	10	1.10	79
Little millet	Bengal gram and amaranth leaf	40	10	1.80	79
Maize meal, white	Cereal alone	—	6	0.32	38
Maize meal, white	Fish flour	10	6.7	1.31	38
Maize meal, white	Food yeast	16	8	1.75	21
Maize meal, white	Soya flour	16	8	1.66	21
Maize meal, white	Skim milk solids	16	8	1.64	21
Maize meal, white	Groundnut meal	16	8	1.21	21
Maize meal, white	Soyabean meal	33	9	1.76	25
Maize meal, white	Groundnut meal	33	9	1.46	25
Maize meal, white	Cottonseed meal	33	9	1.23	25
Maize meal, white	Pea	50	10	1.78	18
Pearl millet	Cereal alone	—	10	1.60	19
Pearl millet	Bengal gram	30	10	2.16	19
Pearl millet	Black gram	30	10	2.10	19
Pearl millet	Green gram	30	10	2.09	19
Pearl millet	Red gram	30	10	2.05	19
Pearl millet	Amaranth leaf	10	10	1.73	19
Pearl millet	Bengal gram and amaranth leaf	40	10	2.22	19
Pearl millet	Black gram and amaranth leaf	40	10	2.04	19
Pearl millet	Green gram and amaranth leaf	40	10	2.30	19
Pearl millet	Red gram and amaranth leaf	40	10	2.25	19
Pearl millet	Coconut cake	40	10	1.60	79
Pearl millet	Coconut cake and red gram	40	10	2.00	79
Ragi	Cereal alone	—	10	2.00	79
Ragi	Bengal gram and amaranth leaf	40	10	2.10	79
Rice	Cereal alone	—	5	1.32	31
Rice	Food yeast	25	5	1.49	31
Rice	Cereal alone	—	10	2.09	19
Rice	Red gram	30	10	2.09	19
Rice	Amaranth leaf	10	10	2.12	19

I	II	III	IV	V	VI
Rice	Red gram and amaranth leaf	40	10	2.18	19
Rice	Cereal alone	—	5	1.54	38
Rice	Fish flour	15	5.9	2.50	38
Rye flour	Cereal alone	—	6	1.29	39
Rye flour	Fish flour	6	6.4	2.17	39
Rye flour	Soyabean flour	62	8	2.43	20
Wheat flour, white	Cereal alone	—	8	0.71	38
Wheat flour, white	Fish flour	8	8.7	1.12	38
Wheat flour, white	Soyabean meal	35	9	2.16	22
Wheat flour, white	Skim milk solids	28	9	1.86	22
Wheat flour, white	Groundnut meal	34	9	1.32	22
Wheat flour, white	Cottonseed meal	32	9	1.29	22
Wheat, whole	Pea	50	10	1.80	18
Wheat, whole	Cereal alone	—	10	1.30	31
Wheat, whole	Food yeast	25	10	1.80	31
Wheat, whole	Cereal alone	—	10	1.77	19
Wheat, whole	Bengal gram	30	10	2.18	19
Wheat, whole	Black gram	30	10	2.15	19
Wheat, whole	Green gram	30	10	2.22	19
Wheat, whole	Red gram	30	10	2.19	19
Wheat, whole	Amaranth leaf	30	10	1.65	19
Wheat, whole	Bengal gram and amaranth leaf	40	10	2.19	19
Wheat, whole	Black gram and amaranth leaf	40	10	2.37	19
Wheat, whole	Green gram and amaranth leaf	40	10	2.23	19
Wheat, whole	Red gram and amaranth leaf	40	10	2.35	19
Legumes and oilseeds					
Bengal gram	—	—	10	1.59	42
Bengal gram	Coconut meal	50	10	2,34	42
Coconut meal	—	—	10	1.98	42
Bengal gram	—	—	10	1.51	41
Bengal gram	Sesame meal	50	10	2.15	41
Bengal gram	Sunflower meal	50	10	2,24	41
Sesame meal	—	—	10	1.73	41
Sunflower meal	—	—	10	2.57	41
Groundnut meal	—	—	10	1.81	42
Groundnut meal	Coconut meal	50	10	2.28	42
Groundnut meal	—	—	10	1.65	41
Groundnut meal	Sesame meal	50	10	1.99	41
Groundnut meal	Sunflower meal	50	10	2.14	41
Groundnut meal	Sesame and Bengal gram flours	50	10	2.03	41
Soyabean	—	—	10	1.73	40
Soyabean	Sesame	35	10	2.17	40
Soyabean milk	—	—	10	2.12	80
Soyabean milk	Sesame	33	10	2.70	80

et al.[43,44] Even though the protein efficiency ratios of groundnut flour and 4 : 1 blend of groundnut flour and skim milk powder were lower than that of skim milk powder (Table IV), the two protein foods when incorporated to provide about 5-10% extra protein in the diets, made up the protein deficiency in the diets and promoted good growth in albino rats. Indian multipurpose food (based on 3 : 1 blend of low-fat groundnut flour and Bengal gram flour and fortified with calcium salts and essential vitamins) when incorporated at 12·5% level so as to provide 4.0-4.5g of extra protein in the diet, supplemented to a highly significant extent poor Indian diets based on rice, wheat, ragi and sorghum comparing well with American multipurpose food based on soyabean meal.[45]

Table IV. *Essential amino acid composition and protein efficiency ratio of some protein-rich foods**

Amino acids (g/16gN)	Protein-rich foods							
	A	B	C	D	E	F	G	H
Arginine	11.1	10.2	10.2	9.8	8.9	5.6	8.6	3.7
Histidine	2.1	2.1	2.5	2.1	2.4	2.8	2.7	2.7
Lysine	3.6	4.4	4.0	4.1	4.9	9.6	6.1	7.9
Leucine	6.9	7.5	6.3	6.5	6.9	7.2	6.8	6.5
Isoleucine	4.6	5.2	4.4	4.5	4.7	5.2	4.9	10.0
Methionine	1.0	1.4	1.1	1.3	1.1	2.8	1.7	2.5
Cystine	1.6	1.5	1.2	1.6	1.6	1.5	1.6	0.9
Phenylalanine	5.1	5.2	5.1	4.9	5.0	3.8	4.6	4.9
Tyrosine	3.6	3.6	3.6	3.0	3.4	2.9	3.4	5.2
Threonine	2.7	3.1	2.9	2.9	3.3	5.8	3.9	4.7
Tryptophan	1.0	1.1	0.9	1.0	1.2	1.1	1.1	1.4
Valine	4.4	4.8	4.9	5.0	5.1	5.4	5.3	7.0
PER	1.50	2.36	1.79	1.87	1.99	2.92	2.56	3.04
Reference No.	(51)	(54)	(51)	(46)	(49)	(51)	(51)	(51)

* (A) Groundnut flour (B) Protein food based on 4:1 blend of groundnut flour and skim milk powder (C) Indian multipurpose food (3:1 blend of groundnut flour and Bengal gram flour) (D) Protein food based on 2:1:1 blend of groundnut and Bengal gram flours and coconut meal (E) Protein food based on 1:1 blend of groundnut and soya flours (F) Fish flour (from oil sardine) (G) Protein food based on 2:1:1 blend of groundnut flour, Bengal gram flour and fish flour (H) Skim milk powder

Protein food based on groundnut and Bengal gram flours and coconut meal: A protein food based on 2 : 1 : 1 blend of groundnut and Bengal gram flours and coconut meal possessed a protein efficiency ratio of 1·9 at 10% level.[46] When incorporated to provide about 5% extra protein to poor diets based on different cereals and 7·5-15% extra protein to tapioca-rice or tapioca maize diets, the protein food made up the protein deficiency in the diet and promoted good growth of rats[47,48].

Protein food based on 1 : 1 blend of groundnut and soya flours: The protein efficiency ratios of protein foods based on 1 : 1 blend of groundnut flour and soya flour and fortified with methionine and lysine have been reported to be as follows[49]: protein food, 2·0; protein food +methionine, 2·5; and protein food+ methionine+lysine, 2·8. When incorporated to provide 10% extra protein in a low-protein tapioca-maize diet, the protein foods were nearly as effective as skim milk powder in making up the protein deficiency in the diet and in promoting good growth in albino rats.[50]

Fish flour and protein food based on 2:1:1 blend of groundnut flour, Bengal gram flour and fish flour: The protein efficiency ratio of the protein food (based on 2:1:1 blend of groundnut flour, Bengal gram flour and fish flour) was 2·6 as compared with a value of 2·9 obtained for fish flour from oil sardine.[51] When incorporated at 10% extra protein level in a low-protein maize-tapioca diet, the protein food was as effective as fish flour in making up the protein deficiency in the diet and in promoting good growth of rats.[52] Fish flour when incorporated to provide 2·5% extra protein in poor Indian diets based on different cereals made up the deficiencies in the diet and promoted excellent growth comparing well with an equivalent amount of skim milk powder.[53]

Conclusion

It is evident from the foregoing account that by a judicious combination of oilseed meals and legumes, it is possible to prepare protein blends having high protein efficiency ratio. Incorporation of fish flour will bring about a further improvement in the nutritive value of the proteins in the blend. Several protein foods having low protein efficiency ratios (ranging from 1·5 to 2·0) have been found to supplement to a highly significant extent poor diets based on different cereals when incorporated to

Table V. *Supplementary value of protein-rich foods to poor quality diets based on different cereals, roots and tubers as judged by the growth of rats*

Protein supplement and diet	Protein content of diet (%)	Duration of experiment (weeks)	Gain in body weight (g/week)	Reference No.
I	II	III	IV	V
Fortified groundnut flour and 4:1 blend of groundnut flour and skim milk powder				
Rice diet	8.0	8	6.9	43
Rice diet + fortified groundnut flour	13.7	8	14.5	43
Rice diet + 4:1 blend of groundnut flour and skim milk powder	13.7	8	15.9	43
Rice diet + skim milk powder	13.7	8	17.5	43
Maize-tapioca diet	5.1	8	0.6	44
Maize-tapioca diet + fortified groundnut flour	19.4	8	17.5	44
Maize-tapioca diet + 4:1 blend of groundnut flour and skim milk powder	19.4	8	18.6	44
Maize-tapioca diet + skim milk powder	19.4	8	19.1	44
Indian multipurpose food				
Rice diet	8.1	8	5.0	45
Rice diet + Indian MPF	12.2	8	14.6	45
Rice diet + American MPF	12.4	8	16.1	45
Wheat diet	11.4	8	7.8	45
Wheat diet + Indian MPF	15.2	8	12.5	45
Wheat diet + American MPF	15.3	8	13.6	45
Sorghum diet	7.4	8	8.4	45
Sorghum diet + Indian MPF	11.6	8	14.0	45
Sorghum diet + American MPF	11.7	8	14.4	45
Ragi diet	6.5	8	8.5	45
Ragi diet + Indian MPF	10.5	8	13.3	45
Ragi diet + American MPF	10.7	8	14.5	45
Protein food containing coconut meal				
Rice diet	8.0	8	4.7	81
Rice diet + protein food	12.7	8	14.3	81
Wheat diet	11.3	8	10.2	48
Wheat diet + protein food	16.2	8	15.9	48
Sorghum diet	7.6	4	7.6	48
Sorghum diet + protein food	12.4	4	14.6	48
Ragi diet	6.6	4	5.6	48
Ragi diet + protein food	11.5	4	14.7	48
Maize diet	8.5	8	8.8	48
Maize diet + protein food	13.5	8	14.2	48
Rice-tapioca diet	5.3	8	4.1	82
Rice-tapioca diet + protein food	12.9	8	15.0	82
Maize-tapioca diet	5.1	8	0.6	47
Maize-tapioca diet + protein food	19.6	8	19.0	47
Protein food based on 1:1 blend of soya flour and groundnut flour				
Rice diet	8.2	4	3.2	49a
Rice diet + protein food	12.5	4	15.5	49a
Rice diet + protein food fortified with methionine	12.7	4	15.8	49a
Rice diet + protein food fortified with methionine and lysine	12.6	4	18.4	49a
Rice diet + skim milk powder	12.5	4	17.8	49a
Maize-tapioca diet	4.6	8	-0.15	50
Maize-tapioca diet + protein food	14.3	8	17.5	50
Maize-tapioca diet + protein food fortified with methionine	14.8	8	18.3	50
Maize-tapioca diet + protein food fortified with methionine and lysine	14.7	8	19.9	50
Maize-tapioca diet + skim milk powder	14.1	8	18.6	50

I	II	III	IV	V
Fish flour (from oil sardine) and protein food containing fish flour				
Rice diet	8.9	8	5.8	53
Rice diet + fish flour	11.3	8	15.1	53
Rice diet + skim milk powder	11.2	8	13.9	53
Wheat diet	12.2	8	7.7	53
Wheat diet + fish flour	14.7	8	15.6	53
Wheat diet + skim milk powder	14.6	8	14.5	53
Sorghum diet	10.7	8	7.2	53
Sorghum diet + fish flour	13.0	8	14.0	53
Sorghum diet + skim milk powder	13.1	8	13.6	53
Ragi diet	8.8	8	7.8	53
Ragi diet + fish flour	11.3	8	13.6	53
Ragi diet + skim milk powder	11.3	8	12.7	53
Maize-tapioca diet	5.6	8	1.8	52
Maize-tapioca diet + fish flour	14.6	8	19.7	52
Maize-tapioca diet + protein food	15.0	8	19.3	52
Maize-tapioca diet + skim milk powder	14.5	8	19.3	52

provide 5% extra protein in the diet.[45,47] If the protein efficiency ratio is as high as that of fish flour or skim milk powder, incorporation of these foods at a lower level so as to provide 2·5% extra protein has been found to make up the protein deficiency in the diet and promote good growth of rats.[53] It is obvious that in the development of protein-rich foods suitable for the treatment and prevention of protein malnutrition in children and other vulnerable sections, the aim should be to have a product with as high a protein efficiency ratio as possible. It should, however, be noted that vegetable protein foods having lower protein efficiency ratio (1·5 to 1·8) than milk proteins and other animal proteins (2.8 to 3.2) can also be effective in making up the protein deficiency in the diet when incorporated in the diet to provide about 5% extra protein.[43-50]

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