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THE ROLE OF PROTEIN QUALITY IN THE DESIGN OF AN INFANT FOOD

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Summary

In the design of an infant food for children aged 6-9 months, 31 nutrients were defined. The costs and compositions of 98 raw materials available commercially in Thailand were fed to a linear programming model and raw materials mixtures selected to give the required levels of the 31 nutrients. The protein quality was defined in terms of amino acid levels, using egg as the reference protein. It was not possible to obtain a feasible solution with the minimum amino acid level above 91% of egg amino acid, which would satisfy the other nutrient requirements. As the mininum amino acid level was increased from 70 to 91%, so the cost increased. There was also variation in the raw materials chosen, as the protein quality was varied. At 70% amino acid level, the protein came mainly from collards, parboiled rice and squid but these were replaced by duck egg and to a lesser extent by sesame as the minimum amino acid level was increased. Protein from duck egg in the mixture increased from 9.42 to 40.12% and sesame from 6.94 to 18.19. There were some collard and sesame at all levels because of their marked contributions to other nutrients, in particular vitamin C and linoleic acid.

The results showed the adaptability of the linear programming model for the study of the effects of compositional change on product design. The method gave a variety of specific mixes from which can be selected the best mix to suit particular circumstances of protein quality, cost, taste preferences, raw material availability, and process applicability.

Introduction

Nutrients from milk are not generally adequate for infant growth and solid food should be given to infants after 3 months, or at the latest 6 months[1]. In Thailand, statistical publications and studies by various researchers have shown the existance of malnutrition in infants[2-4] and the need for a nutritionally adequate food for the weaning period and especially after the first 6 months was emphasized[1]. Research was undertaken to see if a cheap weaning food could be developed using raw materials available in Thailand. The linear programming technique was used in designing the cheapest mix that would satisfy the infant nutritional requirements. The nutritional requirements of an infant were studied and specified, complying with the Notification of the Ministry of Health[5].

The purpose of the present study was to investigate the result of raising the protein quality in the design of an infant food.

Linear Programming Model for Thai Infant Foods

To derive the linear programming model for this study, the infant nutritional requirements and the composition and cost of Thai raw materials were considered.

Infant Nutritional Requirements

In order to narrow the variation in the infant nutritional requirements, the infant age interval chosen in this study was 6-9 months, as it is an age interval that supplementary food is vitally necessary. The description in the Notification was reviewed with information in the literature[6-16] to derive the nutritional infant requirements, which are shown in Table I.

TABLE I: NUTRITIONAL REQUIREMENTS FOR INFANT AGED 6–9 MONTHS

Direct requirement per capita per day	Lower	Upper	Interrelationship of nutrients	Lower	Upper
Calorie, kcal	860	–	*Per 100 kcal*		
Vitamin A, I.U.	–	2150	Protein, g	1.98	3.5
Vitamin D, I.U.	–	400	Linoleic acid, mg	200	–
Calcium, mg	500	–	Vitamin A, I.U.	250	–
Iron, mg	8	–	Vitamin C, mg	10	–
Sodium, mg	161	–	Thiamine, mg	0.05	–
Folic acid, mg	0.05	–	Riboflavin, mg	0.07	–
Copper, μg	–	800	Sodium, mg	–	80
Zinc, mg	–	3.3	Chloride, mg	–	150
			Iron, mg	1	–
Amino acid related to protein (mg/g)			Iodine, mg	5	–
			Vitamin E related to linoleic acid		
			Vitamin E, I.U.		
Isoleucine	37.8	54.0	per 1 g linoleic acid	1	–
Leucine	60.2	86.0			
Lysine	49.0	70.0	*Dried weight related to calorie*		
Cystine + Methionine	39.9	57.0	Calorie, kcal/g dried weight	350	–
Phenylalanine + Tyrosine	65.1	93.0	*Sugar related to carbohydrate*		
Threonine	32.9	47.0	Sugar as percentage of carbohydrate	40	–
Tryptophan	11.9	17.0			
Valine	46.2	66.0	*Calcium to Phosphorus ratio*		
Histidine	15.4	22.0	Calcium, mg/Phosphorus, mg	1.2	2.0

For protein quality, the Notification specified that the consumable value of protein must not be less than 70 percent of egg protein. Therefore, the consumable value of protein was set to be not less than 70 percent of egg protein and expressed in mg/g protein of 11 essential amino acids suggested by FAO/WHO Report in 1971[7]. Table II shows the composition of essential amino acids in egg protein and the values at 70 percent.

TABLE II: ESSENTIAL AMINO ACIDS COMPOSITION OF EGG AND 70 PERCENT OF EGG COMPOSITION.

Amino acid	Egg composition mg/g protein	Composition at 70 percent of egg pattern mg/g protein
Isoleucine	54	37.8
Leucine	86	60.2
Lysine	70	49.0
Cystine + Methionine	57	39.9
Phenylalanine + Tyrosine	93	65.1
Threonine	47	32.9
Tryptophan	17	11.9
Valine	66	46.2
Histidine	22	15.4

Therefore, the lower limit of each amino acid was set to be greater or equal in value to 70 percent of that egg amino acid. Taking isoleucine as an example, the lower limit was expressed in a linear equation of the form:–

$$\text{Cile} = \text{Ile} - 37.8 \text{ Prot} \geqslant 0 \qquad (1)$$

and the upper limit at the value of less or equal to the value of egg amino acid and was expressed in the linear equation of the form:–

$$\text{Dile} = \text{Ile} - 54 \text{ Prot} \ll 0 \qquad (2)$$

Where Cile and Dile represented the lower and upper limits of isoleucine, Ile, represented mg of isoleucine and Prot represented g of protein. The restrictions for the other amino acids were expressed in the same way (Fig. 1).

Raw material and cost

As many as possible Thai raw materials were considered to be input into the linear programming model in order to make the optimization by the linear programming technique as versatile as possible. The raw materials were considered for commercial availability and flavour suitability. With these considerations, 98 raw materials were selected for input into the model. The nutritional composition for all 31 nutrients were sought from 46 publications. The major source of information was the Food Composition Table for Use in East Asia by Department of Health, Education and Welfare, FAO[7]. Cost of the selected raw materials were collected from Monthly Agricultural Economics News[18], Weekly Report of Price, Market Situation of Agricultural Products[19] and Fish Market News[20]. There were 46 raw materials for which costs were not documented and these costs were taken from a market inves-

FIG. 1. MODEL OF LINEAR PROGRAMMING MATRIX FOR THE DESIGN OF INFANT FOOD

Columns / Rows	Raw Materials 98 column	Column with the interrelationship of nutrients													Constraint	
		Other Interrelated nutrients	Amino acid related to protein													
			Prot	Ile	Leu	Lys	Cys	Met	Phe	Tyr	Thr	Trp	Val	His		
Nutrients[a]	Nutrients composition matrix		Zero Matrix												Lower bound	Upper bound
Cile			−37.8	1.0											0	∞
Cleu			−60.2		1.0										0	∞
Clys			−49 0			1.0									0	∞
Csul			−39.9				1.0	1.0							0	∞
Caro			−65.1						1.0	1.0					0	∞
Cthr			−32.9								1.0				0	∞
Ctrp			−11.9									1.0			0	∞
Cval			−46.2										1.0		0	∞
Chis			−15.4											1.0	0	∞
Dile	Zero matrix		−54.0	1.0											−∞	0
Dleu			−86.0		1.0										−∞	0
Dlys			−70.0			1.0									−∞	0
Dsul			−57.0				1.0	1.0							−∞	0
Daro			−93.0						1.0	1.0					−∞	0
Tthr			−47.0								1.0				−∞	0
Dtrp			−17.0									1.0			−∞	0
Dval			−66.0										1.0		−∞	0
Dhis			−22.0											1.0	−∞	0

[a]Cxxx and Dxxx represent the lower and upper limits of the corresponding amino acid Xxx respectively. Standard abbreviations for amino acids are used. Additional abbreviations are: sul = sulfur-containing amino acids; aro = aromatic amino acids.

tigation. Both cost and compositional data of raw materials were expressed per 100 g of edible portion. Appendix I shows the raw materials and their costs used in the model.

The matrix of the raw material compositional and cost data and the infant nutritional requirements

The raw material compositional and cost data were treated as variables, the infant requirements as constraints. The food names were put into the matrix as columns and the nutrient names as rows. The nutritional constraints, or the restriction on the row variables were either incorporated into the matrix as right handside if it was a direct nutritional constraint e.g. calorie requirement, or incorporated as the column elements if it was a nutritional constraint requiring a linear expression of interrelationship between nutrients as in the case of amino acids. The linear programming matrix of the problem is shown in Fig. 1. LPS computer package programme was used with IBM 1130 computer system, 1442 card reader punch and 1132 line printer.

Raising the Protein Quality

The lower limits of the amino acids as related to egg protein were raised at intervals of 10 percent from the original level of 70 percent by LP parametric programme. At the level of 100 percent, an infeasible solution was obtained; henceforward the interval of 1 percent was increased from the lower limit of 90 percent. It was found that the lower limit of amino acid could be raised as high as 91 percent. At this level, leucine, lysine, sulphur amino acids, aromatic amino acids, threonine, tryptophan and valine were at the lower bounded value, i.e. 91 percent, and histidine and isoleucine were at the upper bounds, 100 percent. Therefore, it was very restricted and not possible to raise the lower limit any higher.

Contribution of raw materials in the level studied

There were 6 raw materials coming into the optimum solutions at all levels of the study, i.e. cassava starch, collard, duck egg, sponge gourd, cane sugar and sesame. The other two raw materials that were kept up to the 90 percent level were squid and yellow sweetpotato. Table III shows the composition of food mixes and costs at different levels of amino acid lower limits. The major contribution of these and the other raw materials (examples are shown in Appendix II for amino acid lower level at 70%) are summarized as:–

Buffalo meat:	riboflavin
Cassava starch:	calorie, potassium.
Collard:	protein, β-carotene, thiamine, vitamin E, calcium, iron and iodine.
Duck egg:	retinol, protein, linoleic acid and chloride.
Parboiled rice:	protein

TABLE III: THE COMPOSITION OF FOOD MIXES AND THEIR COSTS AT DIFFERENT LEVELS OF AMINO ACIDS LOWER LIMITS

Cost and composition	Percentage of amino acid lower limits			
	70	80	90	91
Cost, baht	1.779	2.054	2.361	2.562
Total weight, g	454.8	444.7	407.0	434.5
Food raw material, g:				
Cassava starch	48.9	63.4	106.3	114.5
Collard	173.9	177.7	114.0	110.9
Duck egg	14.1	36.2	57.6	60.8
Sponge gourd	12.7	15.3	15.4	14.8
Cane sugar	38.6	38.0	32.8	33.1
Sesame	8.0	6.4	23.1	20.9
Yellow sweet potato	39.2	26.7	19.8	–
Squid	27.4	2.0	2.2	–
Parboiled rice	51.8	41.8	–	–
Brown rice	7.4	16.9	–	–
Buffalo meat	0.1	0.1	–	–
Milled, polished rice	32.7	–	–	–
Black glutinuous rice	–	20.2	–	–
Milled, glutinuous rice	–	–	3.8	–
Whole mungbean	–	–	5.5	3.5
Goabean	–	–	22.0	10.7
Milkfish	–	–	4.5	5.0
Anchovy	–	–	–	0.4
Snapbean	–	–	–	36.5
Ivygourd	–	–	–	2.0
Corn	–	–	–	6.9
Whole cow milk	–	–	–	3.9
Sprouted mungbean	–	–	–	10.7

Sponge gourd:	iodine.
Squid:	protein and iodine.
Cane sugar:	calorie, iron and thiamine.
Sesame:	protein, vitamin E and linoleic acid.
Yellow sweetpotato:	β-carotene and vitamin E.
Black glutinous rice:	linoleic acid and phosphorus.
Whole mungbean:	vitamin E and linoleic acid.
Goabean:	β-carotene and vitamin E.
Milkfish:	iodine.
Snapbean:	β-carotene.
Ivygourd:	β-carotene.
Corn:	vitamin E.
Sprouted mungbean:	vitamin E, riboflavin and iodine.
Brown rice:	phosphorus and chloride.

Milled and polished rice: protein, linoleic acid and potassium.
Milled glutinous rice: thiamine.

Whole cow milk and anchovy had very small significance in contribution due to their small quantities coming in.

The contribution of selected raw materials to increased protein quality

In considering the raw materials' contribution to protein and amino acids at different levels of amino acids studied, the contribution of selected raw materials to protein (Table IV) and the composition of amino acid patterns in the selected raw materials (Table V) were studied.

TABLE IV: THE CONTRIBUTION OF SELECTED RAW MATERIALS TO PROTEIN AT THE DIFFERENT LEVELS OF AMINO ACIDS

Selected raw materials	Percentage contribution to protein at different amino acid lower limits			
	70	80	90	91
Collard	25.79	28.91	17.37	16.72
Duck egg	9.42	26.18	88.83	40.12
Sesame	6.94	6.0	19.93	18.19
Squid	20.83	1.69	1.73	—
Parboiled rice	17.36	15.27	—	—
Brown rice	2.77	7.09	—	—
Whole mungbean	—	—	6.64	4.12

TABLE V: THE AMINO ACIDS COMPOSITION OF SELECTED RAW MATERIALS COMPARED WITH EGG PROTEINS

Amino acid	Hen egg	Collard	Duck egg	Sesame	Squid	Parboiled rice	Brown rice	Whole mungbean
Isoleucine	54	60	64	55	50	51	48	41
Leucine	86	66	91	92	68	94	90	70
Lysine	70	62	81	37	79	36	41	93
Cystine + Methionine	57	19	85	50	38	53	40	25
Phenylalanine + Tyrosine	93	70	98	105	73	108	103	79
Threonine	47	46	43	56	33	48	40	32
Tryptophan	17	12	17	16	8	12	13	19
Valine	66	52	74	67	64	77	67	43
Histidine	22	18	21	32	17	31	25	29

At 70 percent level—Collard, squid and parboiled rice were the main contributors to protein, duck egg contributed only 9.4 percent. Though collard and squid pattern of amino acid were poor, they were supplemented by small amounts of duck egg and parboiled rice to satisfy the lower bound at 70 percent.

At 80 percent level–Squid decreased markedly in its contribution and was substituted by duck egg which increased its contribution to total proteins to 26.2 percent, making itself and collard the major contributors to protein and amino acid. Parboiled rice and brown rice were the next contributors because of their high leucine content; this was low in collard even after the supplementation from duck egg.

At 90 percent level–Sesame started to contribute to protein and amino acid more than collard because of its high content of aromatic amino acid and threonine which were low in the combination of duck egg and collard. The new raw material which started to come in was whole mungbean, having high lysine supplemented to the low content in sesame.

At 91 percent level–Duck egg contributed to 40.1 percent of protein, it supplemented well with sesame for sulphur amino acid, aromatic amino acid and threonine. The combination of the two raw materials, duck egg and sesame supplemented collard of which the quality of protein was poor especially in sulphur amino acid, aromatic amino acid and leucine.

The effect of raising protein quality on cost, prices, practicability and eating preference

The cost of the mix increased directly with the increase in amino acid level. The ratio of cost per percentage increment of amino acid increased very slightly from the level of 70 percent to 90 percent i.e. 0.0275 to 0.0307 baht, but increased markedly from the level of 90 to 91 percent i.e. 0.201 baht.

The number of raw materials coming into the solution was 12 from the lower limits of 70 percent to 80 percent, and increased to 13 at 90 percent and 15 at 91 percent. The increased in the number of raw materials makes it more difficult to obtain or cook the raw materials. It is more so if it is going to be manufactured because of the difficulty in controlling the raw materials' qualities and the process. Therefore, as far as preparation and processing are concerned, the smaller number of raw materials would be more practical.

The variations in the mixes were quite considerable, ranging from a fair amount of collard, some squid and small amounts of egg to a mix with a fair amount of cassava starch, collard and some egg. This offers choices in the selection of the mixes that will be most acceptable to the infant. Hence, raising the protein quality gave variations of raw materials in the food mix so that choice could be made according to preference as well.

Conclusion

In the design of an infant food by the linear programming technique, it was possible to obtain the cheapest mix satisfying the requirements of infants aged 6–9 months from vegetables, cereals with a small amount of animal protein such as squid and duck egg. However, when protein quality was increased, egg proteins substituted other sources of protein considerably; as did sesame to the lesser extent.

Raw materials consistently coming into the solution were cassava starch, sucrose and sponge gourd for their contribution to other nutrients. Nevertheless, it is not possible to raise the level of amino acid higher than 91 percent with the other nutrients requirements fulfilled.

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บทคัดย่อ

ในการพิจารณาอาหารทารกอายุ 6–9 เดือน สารอาหารจำนวน 31 ประเภท ได้ถูกกำหนดตามความต้องการของทารก วัตถุดิบจำนวน 98 ชนิด ได้รับการพิจารณา และ linear programming model ได้ถูกสร้างขึ้นเพื่อทำการเลือกวัตถุดิบต่าง ๆ เพื่อให้ได้คุณค่าทางอาหาร 31 อย่าง ที่ได้กำหนดไว้

คุณภาพของโปรตีนขั้นต่ำได้ถูกกำหนดขึ้นโดยต้องไม่น้อยกว่าร้อยละ 70 ของโปรตีนจากไข่ การศึกษาในอันที่จะยกคุณภาพของโปรตีนขั้นต่ำ พบว่าสามารถจะยกขึ้นได้สูงสุดถึงร้อยละ 91 โดยคงไว้ซึ่งความต้องการของสารอาหารที่กำหนดไว้ในตอนต้น โดยการใช้ linear programming model สามารถจะแสดงให้เห็นว่าเมื่อคุณภาพของโปรตีนเพิ่มขึ้น การใช้วัตถุดิบและราคาของส่วนผสมเปลี่ยนแปลงไปอย่างไร ทำให้สามารถจะเลือกส่วนผสมที่เหมาะสมที่สุดตามคุณภาพของโปรตีน ราคา รสชาด วัตถุดิบและขบวนการผลิตที่ต้องการ

APPENDIX I. FOOD RAW MATERIALS AND THEIR COSTS, PER 100g EDIBLE PORTION, USED IN THE LINEAR PROGRAMMING MODEL.

Raw materials	Cost (baht)	Raw materials	Cost (baht)	Raw materials	Cost (baht)
1. Cereals; starchy roots, tubers; legumes; nuts and seeds					
Cashew nut	7.0000	Cassava	0.1027	Cassava starch	0.4000
Cowpea, dry	0.5000	Coconut	0.6000	Mungbean, whole	0.4700
Mungbean, starch	0.6500	Peanut, raw, with shell	0.3846	Peanut, dry and shelled	0.7000
Pigeon pea	0.6294	Rice, black, glutinous	0.3500	Rice, brown	0.4000
Rice flour	0.6000	Rice, glutinous flour	0.7000	Rice, glutinous milled	0.3500
Rice, milled and polished, 5%	0.3470	Rice, parboiled	0.4204	Sesame	1.0660
Soybean	0.4500	Soybean curd	1.2000	Soybean flour	0.7500
Sweet potato, white	0.1724	Sweet potato, yellow	6.1724		
2. Vegetables					
Bamboo	0.7143	Beans, snap	0.3158	Cabbage	0.4070
Cabbage, chinese	0.4069	Cauliflower	0.9167	Collard	0.3378
Cowpea, yard long	0.2273	Goabean	0.3158	Ivygourd	0.6000
Peas	2.1053	Mustard, green	0.6667	Sprouted mungbean	0.2151
Swampcabbage	0.1467	Bottle gourd	0.3353	Carrot	2.6506
Corn	0.5405	Corn small	4.0000	Cucumber	0.3346
Eggplant	0.3240	Mushroom	1.6484	Pumpkin	0.2989
Radish	0.2409	Snake gourd	0.2222	Sponge gourd	0.2532
Wax gourd	0.2111	Tomato	0.3723		
3. Fruit					
Banana, common variety	0.4760	Banana 2	0.9060	Grape	1.9231
Guava	0.4082	Lemon	0.7463	Orange	0.9375
Orange, mandarin	0.8571	Papaya	0.2778	Pineapple	0.3636
Water melon	0.2542				
4. Meats and poultry					
Beef	3.5294	Buffalo	3.0000	Chicken, matured	2.6250
Chicken, young	2.8000	Duck	2.5000	Liver, beef	3.2908
Liver, chicken	3.6082	Liver, duck	3.6082		
Liver, hog	3.9175	Pork, lean	3.9024	Heart, beef	2.6804
Heart, hog	4.1237	Brain, hog	6.1857	Gizzard, duck	3.6082
Gizzard, chicken	3.6082				
5. Eggs and milks					
Egg, hen	1.9318	Egg, duck	1.4848	Whole cow milk	1.1110
Milk, dry	5.0000	Skim, fluid	1.1110	Skim, dry	5.0000
6. Fish and shellfish					
Anchovy	2.4658	Catfish, fresh water	2.6322	Catfish, sea water	2.4490
Carp	1.9300	Dorab	1.5405	Eel	2.8571
Gouramy	2.1054	Hardtail	1.7391	Spanish mackerel	2.9231
Stripe mackerel	2.1930	Milkfish	2.1739	Mullet	3.3077
Prawn, river	9.3910	Prawn, sea	12.0000	Perch	2.0816
Snapper	2.0816	Serpenthead	2.7272	Squid	1.6130

APPENDIX II. THE COMPOSITIONS OF OPTIMUM SOLUTION AT 70% AMINO ACID LOWER LIMIT AND THE CONTRIBUTION OF SELECTED RAW MATERIALS TO THE NUTRIENTS STUDIED

Nutrients	Solution composition	Percentage contribution of selected raw materials											
		Buffalo Meat	Cassava Starch	Collard	Duck egg	Brown rice	Milled, polished rice	Parboiled rice	Sponge gourd	Squid	Su-crose	Yellow Sweet-potato	Sesame
Calorie, kcal	860.00	.01	20.12	7.08	3.08	2.96	13.95	21.98	0.27	2.39	17.46	5.24	5.46
Protein, g	0.08	1.24	25.79	9.42	2.77	10.41	17.36	0.69	20.83	2.08	2.33	6.	–
Fat, g	8.40	–	–	–	23.80	–	–	–	–	–	–	–	–
Fiber, g	3.42	61.42											12.57
Calcium, mg	500.00			79.98									12.0
Phosphorus, mg	416.67				7.43	4.36		16.77		12.76			11.75
Iron, mg	9.35			37.41							23.94		10.26
Sodium, mg	180.42			1.20	14.96								
Potassium, mg	1916.14	23.63		44.46			4.12				6.52		
Retinol,/μg	56.25				92.8					7.23			
β-carotene,/μg	1176.28			39.95	2.21							56.02	
Thiamine, mg	0.67			25.41							28.44		8.98
Riboflavin, mg	0.60				9.96								
Vitamin C, mg	174.76			92.52								6.75	
Folic acid, mg	0.85			94.02									
Iodine,/μg	43.00		3.1	37.9	3.25			2.32	36.04	14.41			
Vitamin E, I.U.	2.06				15.07								40.85
Chloride, mg	197.74			35.02		4.87	4.47	7.06		27.44			
Linoleic acid, mg	1720.00				8.09		3.43	6.62					77.67
Isoleucine, mg	1057.70			25.59	11.34		9.17	16.92		19.94			7.18
Leucine, mg	1540.90			22.32	10.96		11.87	21.29		18.49			8.24
Lysine, mg	1145.30			28.11	13.18		8.12	11.17		28.72			4.45
Methionine, mg	524.40			8.96	25.55		9.72	24.98		19.45			10.10
Cystine, mg	258.10			20.92	9.29		10.46	22.85		22.47			6.19
Phenylalanine, mg	1031.60			28.79	9.88		11.53	19.77		14.92			8.53
Threonine, mg	846.10			28.36	9.57		9.8	19.85		16.31			9.10
Tryptophan, mg	283.80			22.19	11.27		9.51	15.15		12.33			8.10
Tyrosine, mg	647.83			10.49	12.34		9.41	27.0		22.99			8.79
Valine, mg	1248.70			21.70	11.05		9.85	21.62		21.46			7.36
Histidine, mg	441.40			20.84	9.06		10.19	24.92		15.63			9.96