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Construction of Healthy and Palatable Diet for Low Socioeconomic Female Adults Using Linear Programming

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Abstract*— Differences in the socioeconomic profile may influences healthy food choices, particularly among individuals with low socioeconomic status. Thus, high-energy dense foods become the preferences compared to high nutritional content foods due to their cheaper price. The present study aims to develop healthy and palatable diet at the minimum cost based on Malaysian Dietary Guidelines 2010 and Recommended Nutrient Intake 2005 via linear programming. A total of 96 female adults from low socioeconomic families in Johor, South East Malaysia have been recruited for the present study. Anthropometric measurement; weight and height, socio-demographic information and 3-days food record have been collected from the subjects. In addition, data on food prices have also been collected. Then, a linear programming model has been developed to select the cheapest food combinations that could fulfil all the nutritional recommendations and palatable constraints in order to capture common dietary habit of the locals. Subsequently, healthy seven-days menus have been created using the optimal food servings estimated from the linear programming model. Dietary data have shown that the average energy intake among low-income adult women (1871 ± 317 kcal/day) is less than the nutrient recommendation. Thus, from the linear programming analysis, the minimum food cost has been estimated at RM6.55 (2.15 USD) for the total energy intake of 2000 kcal per day for a female adult which meets the recommendation of MDG 2010 and RNI 2005. In conclusion, linear programming may be a useful tool to develop healthy and palatable diets at a minimal cost in managing dietary problems among low socioeconomic groups where food expenditure becomes an important restraining factor. Eventually, low socioeconomics female adults would improve their nutritional intake by making wiser food choices to meet all the nutritional requirements, which lead to healthier life.

***Keywords*— socioeconomic status; linear programming; constraints; healthy diet**

I. Introduction

A healthy diet may improve productivity for all ages and it helps in the reduction and prevention of health problems such as chronic diseases and malnourishment from occurring [1]. Healthy diets are obtained by taking foods that contain nutrients in the recommended dose [2]. One's socioeconomic status is measured either by the income level, occupation or education. It has been revealed that socioeconomic status plays a major role in eating patterns and food choices. Thus, the socioeconomic status may be one of the factors that could cause unhealthy eating behaviour among people with low socioeconomic status [3].

Several studies have shown that energy-dense foods are foods that are commonly chosen by the low socioeconomic class due to their cheaper price [4]. These energy-dense foods are usually high in fat. Furthermore, diets among low socioeconomic individuals have been related to low consumption of fruits and vegetables. It has been explained that high nutritional value foods like fresh fruits and vegetables are expensive and as a result, cheaper food which has less nutritional value is favored among the low-income group [5]. Moreover, the low-income group is prone to consume cheaper foods which satisfy their hunger, rather than buying nutritious foods [6].

Low intake of fruits and vegetables among low socioeconomic adults has been reported in France, where it has been linked to psychosocial, educational, economic and material barriers [7]. This was probably due to a limited household budget and low nutritional knowledge in making healthy food choices. Besides, unhealthy eating patterns among the low-income group eventually would lead to health problems such as obesity, hypertension, heart diseases and diabetes. In the United States, the prevalence of overweight and obesity has been reported to be higher in low-income households and educational level [8], [9].

In Malaysia, based on the Malaysian Adult Nutrition Survey (MANS), most of female adults did not fulfill the recommendations for iron and calcium [10]. Despite the poor dietary habits, the prevalence of obesity and overweight was higher in women than men. An earlier research by [11] found that women were significantly more obese than men. In addition, the mean Body Mass Index (BMI) of female adults (24.6 kg/m^2) was significantly higher than the mean BMI among adults (24.2 kg/m^2). If this scenario is not prevented or overcome, it may lead to more complicated conditions especially among a vulnerable group like the low-income people. The encouragement toward healthy balanced diet among the low-income group may improve their overall health status and eventually reduce the prevalence of chronic diseases in Malaysia.

Linear programming has been defined as a technique used in minimizing a set linear function of variables while relating multiple linear constraints. Basically, the technique is based on a mathematical approach [12]. Furthermore, it is one of the techniques that can be used in planning healthy diet menus where nutrient requirements can be achieved at the lowest cost [13]. Hence, this study aims to develop a healthy diet based on the Malaysian Dietary Guidelines (MDG) 2010 (NCCFN 2010) and Recommended Nutrient Intake (RNI) 2005 at a minimal cost and at the same time palatable for consumption among low socioeconomic female adults [14].

II. Material and Method

Study design and sampling method: This study had been approved by Research Ethics Committee of Universiti Kebangsaan Malaysia (UKM) before two phases of data collection were conducted between March-April 2013. A cross-sectional study was done among 96 female adults at several low-cost flats at Taman Chendana in Pasir Gudang, Johor (South of Malaysia), which aged 19-59 years. The inclusion criterion was total household income < RM3000 (USD 932.40) per month. In the second phase, a survey was conducted to obtain the food prices which were used in the LP model to develop seven-days menus for 2000 kcal.

A. Data Collection

An interview-based questionnaire was distributed to subjects in the first phases to assess their socio-demographic profile and eating patterns. Anthropometric measurements including height and weight were measured using SECA Bodymeter model 208 and Tanita HD 309 respectively. Eating patterns of the subjects were assessed by three-day food records, where the subjects had to document their food intake for two days in a week and one over the weekend.

Based on the subjects eating pattern information, the price for each food items was obtained from the Ministry of Domestic Trade, Cooperative, and Consumerism (KPDNKK). The food prices were set in terms of price per serving size. Nutrient Composition of Malaysian Foods [15] was used to determine the nutrient content i.e. energy, macro-nutrients and some micro-nutrients such as calcium, iron, vitamin A, vitamin C and fibre for each food items. Both prices and nutrients were then fed into the LP model.

B. Data Analysis

All data in both sets of questionnaire were analyzed using Statistical Package for Social Sciences (SPSS) version 20.0. The results were presented descriptively for categorical data while means and standard deviation were calculated for continuous data. Nutritionist Pro software was used to assess dietary intake data prior to analysis by SPSS. Next, Excel Solver was utilized to develop the LP model in finding optimal food servings with the lowest cost. The model should have achieved the recommended dietary and nutrient requirements based on the Malaysian Dietary Guidelines (MDG 2010) (NCCFN 2010) and Recommended Nutrient Intake (RNI 2005) [14].

C. Linear Programming Model

The model used in LP was specified as follows

$$\text{Min } z = \sum c_j x_j$$
$$\text{Subject to: } b_i \leq \sum a_{ij} x_j \leq b_i$$
$$x_j \geq 0$$

The objective of the model was to minimize food cost, z (in RM). The quantity of food item j (in kg) is represented as X_j; a_{ij} denotes the amount of nutrient i in one kilogram of food item j; C_j was the cost of a kilogram of food item j; b_i denotes the largest or smallest acceptable quantity of nutrient i. The constraints in the model for this study were MDG 2010 and RNI 2005. Palatability constraints were also included to ensure that the suggested menus were suited to the subjects' common food pattern. These constraints have been listed in Table 1.

There are seven food groups in MDG; cereals, grains, fruits, vegetables, meat/poultry, fish, legumes, milk and dairy products. The constraints included in the LP consist of the lower bound and upper bound values of MDG 2010 in terms of serving size. Energy, carbohydrate, protein, fat, calcium, iron, vitamin A, vitamin C and fibre were included as RNI constraints. The lower bound and upper bound of the nutrients were based on RNI 2005. In order to make the menus palatable; oils (palm oil and vegetable oils) and sugar were added where one serving of oils was equivalent to two teaspoons and one serving of sugar was defined as five teaspoons per day.

These constraints were placed together with prices and nutrient composition in the LP model. Once the software was run, the minimum cost and the selected raw food items were considered as a model.

TABLE I
VALUES OF LOWER BOUND (LB) AND UPPER BOUND (UB) OF MDG 2010, PALATABILITY AND RNI 2005 CONSTRAINTS

Constraints	LB	UB
MDG 2010		
Cereals and grains (serving)	6	8
Fruits (serving)	2	3
Vegetables (serving)	3	5
Meat/poultry (serving)	1	2
Fish (serving)	1	3
Legumes (serving)	0.5	1
Milk and dairy products (serving)	2	3
Palatability		
Vegetable oil (serving)	1	2
Palm oil (serving)	1	2
Sugar (serving)	1	2
RNI 2005		
Energy (kcal)	1800	2000
Protein (g)	50.0	100.0
Carbohydrate (g)	275.0	300.0
Fat (g)	44.0	67.0
Calcium (mg)	800.0	2500.0
Iron (mg)	29.0	45.0
Vitamin A (µg)	500.0	3000.0
Vitamin C (mg)	70.0	2000.0
Fiber (g)	20.0	30.0

III. RESULTS AND DISCUSSION

A. Socio-Demographic Data

The socio-demographic characteristics of female adults are shown in Table 2. The mean age among 96 women subjects was 41.4 years where more than half of them were aged between 40 to 49 years. With regard to ethnicity, there were 97.9% Malays, 1.0% Indians and 1.0% from other ethnic races. Regarding the marital status, 86.5% were still married, 6.3% widowed and the remaining 7.3% were either divorced or separated. Based on the results, only 1.0% had never attended school, 18.8% completed primary schooling, 77.1%, and 3.1% finished secondary schooling and university education respectively.

A total of 72.9% of the female adults were categorized as having low household income (< RM 2000) with the mean income of 1599.59 ± 620.98 per month according to the Department of Statistics, Malaysia (2007) [16]. The highest household income among the subjects was RM 3000, which was classified as the middle-class income. About 56.3% of the subjects distributed from RM 1001 to RM 2000 of their income for expenses on food, transportation, clothes and others, whereas the mean income distribution was RM 1291.71 ± 479.41.

B. Anthropometric Data

The results from this study showed that 36.0% were under the category of normal BMI (BMI: 18.5 kg/m^2 to 24.9 kg/m^2), while 33.6% were having BMI more than 25 kg/m^2 which can be classified as either overweight or obese. These BMI categories are: underweight, normal, overweight and obese, based on WHO Expert Consultation 2004 [17].

C. Dietary Pattern

Table 3 shows the calories and nutrient intake with the percentage of subjects achieving RNI. The mean energy intake was 1871 ± 317 kcal which was lower than the RNI recommendation (2180 kcal), and only 20.5% of the subjects met the RNI requirements. The mean percentage of the subject's carbohydrate intake was 52.1 ± 4.9% which contributed about 52.0% of the total energy intake, while protein contributed about 15.0% and 30.0% of the total energy intake was contributed by fat. About a quarter of the subjects (25.6%) met the requirement for carbohydrate; whereas for protein and fat, 39 subjects met the requirements.

In this study, no subject met the requirement for iron and folic acid, where intakes of 17.50 ± 5.23 mg and 97.52 ± 34.84 µg were recorded respectively. Other micronutrients intake such as calcium, zinc, B1, B2, B3 and vitamin C were also poor in the subjects' dietary habits. The only vitamin which was fulfilled by the subjects was vitamin A with a level of 17860 ± 752.13 µg reported.

D. Development of Healthy and Palatable Menu

Table 4 shows the comparison of food groups by the four LP models based on MDG 2010, palatability and RNI 2005 as the constraints for the total energy intake of 2000 kcal/day. LP models should satisfy the upper and lower limit of the constraints which include the serving size of seven types of food groups (cereals and grains, fruits, vegetables, meat and poultry, fish, legumes, milk and dairy products) based on MDG 2010, the serving size of vegetable oils, palm oils and sugar as the palatability constraints and nine essential nutrients recommendation (macro-nutrient and micro-nutrient) based on RNI 2005.

In this study, it was found that all the constraint values for the four LP models were in the range of MDG, palatability and RNI constraints. Fat, calcium and vitamin C were in moderately acceptable limits while energy, iron, and fiber only reached the lower limit of the constraint values. Other nutrients such as carbohydrate (CHO), protein, vitamin A and fiber reached the upper limit of the maximum acceptable value of RNI constraints for these nutrients. As a result, seven-day healthy and palatable menus have been developed according to MDG 2010 and RNI 2005 for low socioeconomic female adults in Taman Chendana.

The menus have been developed according to raw food materials at the lowest cost based on MDG, RNI and palatability constraints by using LP as shown in Table 5. It has been estimated that the minimal food cost for adult women in Taman Chendana is RM6.55 (2.15 USD) per day for total energy intake 2000 kcal. Furthermore, the minimal cost had considered foods that meet nutrient recommendations with the palatability and eating habits of female adults in Taman Chendana are taken into account.

The present study shows a healthy and palatable menu at minimal cost for low socioeconomic female adults through the adoption of LP can be developed. Besides, the menu is able to meet the daily nutritional requirements based on MDG 2010 and RNI 2005. This LP model has also been used widely in the United States where it has helped low socio-economic households achieved nutritional recommendations at minimal cost based on Dietary Guidelines. Furthermore, including the general nutrient recommendations into low socio-economic, female adults' practice was a challenge as the population eating habits, food prices and diet costs need to be taken into consideration [18].

The dietary patterns of low-income female adults in Taman Chendana showed that the intake of several micronutrients such as iron, calcium, and zinc did not meet the nutritional requirement that has been recommended. Limited food expenses among low-income female adults have made them unable to afford healthy foods such as fruits and vegetables which are high in nutrient content [19]. Lack of iron, calcium and zinc intake among the subjects was probably due to their tendency to choose non-green vegetables such as carrots, tomatoes, and cabbage that are usually high in vitamin A. Furthermore, most low-income consumers prefer to buy foods which are sources of vitamin A [20].

TABLE III
SOCIO DEMOGRAPHIC CHARACTERISTICS OF FEMALE ADULTS (N = 96)

Characteristics	N	%	Mean	Range
Age (years)				
30-39	38	39.6	41.42 ± 4.35	32-51
40-49	54	56.3		
≥ 50	4	4.2		
Ethnic				
Malay	94	97.9		
Indian	1	1.0		
Others	1	1.0		
Marital status				
Married	83	86.5		
Widowed	6	6.3		
Divorced/separated	7	7.3		
Educational status				
No formal education	1	1.0		
Primary school	18	18.8		
Secondary school	74	77.1		
Tertiary education	3	3.1		
Household size				
< 3	1	1.0		2-11
3-6	59	61.5		
7-10	35	36.5		
≥ 11	1	1.0		
Household income (RM)				
< 2000	70	72.9	1599.59 ± 620.98	150.00-3000.00
2000-3999	26	27.1		
≥ 4000	0	0		
Household expenditures (RM)				
≤ 1000	35	36.5	1291.71 ± 479.41	567.00-2690.00
1001-2000	54	56.3		
2001-3000	7	7.3		

TABLE IIIII
CALORIES AND NUTRIENT INTAKE WITH THE PERCENTAGE OF SUBJECTS ACHIEVING RNI (N = 39)

Nutrients	Mean intake	Percentage of subjects achieving RNI
Energy (kcal)	1871 ± 317	20.5
Protein (g)	70.35 ± 13.07	92.3
Energy percentage from carbohydrate (%)	52.11 ± 4.94	25.6
Energy percentage from protein (%)	15.45 ± 1.66	100
Energy percentage from fat (%)	32.43 ± 4.75	100
Calcium (mg)	528.89 ± 266.25	12.8
Iron (mg)	17.50 ± 5.23	0
Zinc (mg)	3.53 ± 1.16	15.4
Thiamine (mg)	0.72 ± 0.33	10.3
Riboflavin (mg)	1.09 ± 0.42	33.3
Niacin (mg NE)	10.04 ± 3.26	15.4
Folic acid (µg)	97.52 ± 34.84	0
Vitamin C (mg)	58.50 ± 40.66	25.6
Vitamin A (µg)	1786.80 ± 752.13	100

TABLE IV
COMPARISON OF FOOD GROUPS BY THE FOUR MODELS WITH MDG, PALATABILITY AND RNI CONSTRAINTS FOR 2000 KCAL

Constraints	**LB**	**UB**	**Model I**	**Model II**	**Model III**
MDG 2010					
Cereals and grains (serving)	6	8	6.5	6	6
Fruits (serving)	2	3	3	3	2
Vegetables (serving)	3	5	3	4	4
Meat/poultry (serving)	1	2	1.5	1	1
Fish (serving)	1	3	1	2	2
Legumes (serving)	0.5	1	1	1	1
Milk and dairy products (serving)	2	3	2	2	3
Palatability			2	2	2
Vegetable oil (serving)	1	2	1	1	1
Palm oil (serving)	1	2	1	1	1
Sugar (serving)	1	2			
RNI 2005					
Energy (kcal)	1800	2000	2000	2000	2000
Protein (g)	50.0	100.0	100.0	100.0	100.0
Carbohydrate (g)	275.0	300.0	300.0	300.0	300.0
Fat (g)	44.0	67.0	54.2	50.4	51.2
Calcium (mg)	800.0	2500.0	1243.8	1053.0	1115.9
Iron (mg)	29.0	45.0	29.0	29.0	29.0
Vitamin A (µg)	500.0	3000.0	3000.0	3000.0	3000.0
Vitamin C (mg)	70.0	2000.0	470.2	650.4	649.3
Fiber (g)	20.0	30.0	20.0	30.0	30.0
Cost (RM)			6.55	8.91	10.44

TABLE V
DEVELOPMENT OF SEVEN-DAY MENU PLANNING FOR 2000 KCAL WITH MINIMAL COST PER DAY

Meals	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
Breakfast	Fried, noodles Tea	'Kampong' Fried rice Tea	'Kampong' Fried rice Tea with low-fat milk Banana	Noodles, soup Tea	Pancake, wheat Tea	2 pieces white bread ¼ teaspoon of margarine 1 glass of low-fat milk	Fried, noodles Tea
Morning tea	2 pieces of sardine bun Tea	2 pieces of sardine sandwich Tea with low-fat milk	1 glass of full cream milk	6 pieces cekodok pisang Tea with low-fat milk	2 pieces toasted bread 1 glass of low-fat milk	Pancake, wheat Tea	2 pieces of toasted bread 1 glass of low-fat milk
Lunch	Cooked, rice Sardine, fried in chili Spinach, in water Guava	Cooked, rice Sardine, curry Kerabu tau geh Pineapple	Cooked, rice Indian mackerel, cooked in tamarind String bean, fried Guava	Cooked, rice Ikan kembong kecil masak singgang String bean, fried Guava	Cooked, rice Catfish, cooked in coconut milk (grilled) Sambal jawa Sayur campur goreng Guava	Cooked, rice Hairtail scad, fried in chili Sayur capcai goreng Guava	Cooked, rice Hairtail scad, fried Sayur masak lodeh Guava
Afternoon tea	2 pieces of white bread 1 glass of full cream milk	2.pieces of white bread 1 glass of full cream milk	Pancake, wheat Tea	1 glass of full cream milk	1 glass of full cream milk	1 glass of full cream milk	1 glass of full cream milk
Dinner	Cooked, rice Chicken breast, cooked in soy sauce Egg Bean sprouts with tofu, cooked in coconut milk Pineapple	Noodles, tom yam Guava	Noodles, soup Tea	Cooked, rice Quail egg, fried in chili Swamp cabbage, fried Guava	Cooked, rice Hairtail scad, grilled Pencicah Swamp cabbage, fried Guava	Cooked, rice Catfish, cooked in chili Swamp cabbage, fried Guava	Cooked, rice Fried Catfish, Swamp cabbage fried Guava
Food cost per day (RM)	6.55	6.55	8.91	8.91	10.44	10.44	10.44

Moreover, most of the subjects preferred not to consume milk and dairy products. This has to be the reason, why the dietary analysis showed that there was a lack of calcium consumption. According to [10], the mean intake of iron and calcium among Malaysian female adults has been reported to be lower than the nutritional requirements. Unfortunately, these micronutrients may be found in healthy food such as green vegetables, fruits, milk and dairy products, which are expensive for the low-income groups. This result was consistent with the study performed by [21], which reported that most of low socio-economic adults tend to buy unhealthy food items like energy-dense foods and processed foods which have poor nutritional content.

Thus, the LP model has been used in this study in order to overcome dietary problems among low-income female adults to achieve a healthy diet. The application of this LP model was important in identifying nutritionally adequate diet at a minimal cost, where the collection of local food prices is linearly related to food weight [12]. Hence, through the adoption of LP model, the minimum food cost was RM6.55 (2.15 USD) per person per day. Furthermore, a variety of meals could be prepared and presented differently for seven days which include six types of meals from breakfast to supper. All these menus meet the daily nutritional requirement for adults at a minimal cost only.

However, there were a few limitations in developing the model using the LP analysis. We had to exclude several food items in order to generate the second and third cheapest optimal food choice to avoid repetition of food choices. Therefore, we only ran the program three times to find the minimum food cost and choices. As we made more exclusion, the cost continued to rise and appeared unaffordable for the low socioeconomic groups. Furthermore, there were too many constraints and expectations for the food items which resulted in making the model become unfeasible. Therefore, more lists of food items should be included in the model to reduce the limitations in future studies.

This study has revealed that healthy and palatable menus can be developed for low socioeconomic female adults by using the LP model at a minimal cost. In addition, poor dietary [22], [23] intake may be improved using this model where it follows the MDG, RNI and palatability constraints to meet the nutritional requirements.

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