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Development of Healthy Menus at Minimum Cost for Older Adults Using a Diet Optimization Model

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ABSTRACT

Background: The number of older adults in developing countries is growing rapidly, posing challenges related to malnutrition due to unbalanced diets. Food cost is one of the barriers to consuming nutritious foods. This study aims to develop optimized healthy menus for 1800 kcal and 2000 kcal diets at minimal cost using mathematical programming. **Methods:** Data were obtained from phase IV of the Long Term Research Grant Scheme Towards Useful Aging cohort study (LRGS-TUA), involving 246 purposively sampled older adults (≥60 years) from 10 areas in Selangor, Malaysia. Sociodemographic, anthropometric, and nutrient intake data were analyzed. The Diet Optimization Model was applied to develop healthy, low-cost menus for older adults based on the recommended nutrient intakes for Malaysia (2017). **Results:** Among 246 older adults, 38.6% were overweight, and 71.5% lived below the poverty line. Energy and key micronutrient intakes such as fibre, calcium and potassium were well below daily recommendations, while sodium exceeded the upper limit. The diet optimization model produced nutritionally adequate menus at a minimum cost of RM8.00 (1800 kcal) and RM8.69 (2000 kcal). **Conclusion:** The diet optimization model demonstrated that affordable, nutritionally adequate menus for older adults can be achieved at minimal cost that meet nutritional requirements, offering a practical strategy to improve diet quality and reduce nutrition inequities among low-income elderly populations. Future studies should be conducted among older adults of varying socioeconomic and cultural backgrounds, food preferences, and habits to evaluate the model's generalizability.

Introduction

The global elderly population is rising rapidly, with projections reaching 2.1 billion by 2050 (World Health Organization, 2017). Developing countries are experiencing faster growth in aging

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populations, impacting health expenditures (Baharin and Saad, 2018). Data from the National Health and Morbidity Survey (NHMS) reported that 7.3% and 23.5% of older adults in Malaysia are malnourished and at risk of malnutrition (Ahmad *et al.*, 2021) while overweight and obesity rates stand at 37% and 17.6%, respectively (Shariff Ghazali *et al.*, 2021). An unbalanced diet contributes to malnutrition, micronutrient deficiencies, and degenerative diseases (Lau *et al.*, 2019, Maggini *et al.*, 2018). A study conducted among older adults in two states in Malaysia reported that ageing, low niacin intake, depression and lack of social support could lead to cognitive impairment (Malek Rivan *et al.*, 2019).

As a significant lifestyle factor, diet influences the risk of various chronic conditions such as obesity, hypertension, metabolic syndrome, type 2 diabetes, cardiovascular disease, stroke, certain cancers, and possibly neurological disorders (Gropper, 2023). A nutrient profiling model developed for older adults reported an inverse correlation between nutrient profiling models and energy density, indicating that foods with greater nutrient density tend to have lower energy content (Mohamad Basiran *et al.*, 2018). One major barrier to adequate nutrition is cost. Financial constraints and high food costs limit access to nutritious diets, particularly for low-income older adults in Malaysia (Leng *et al.*, 2016). Although guidelines provide nutrient targets, they do not account for affordability, making adherence difficult for low-income groups. As a result, many older adults rely on cheaper, calorie-dense but nutrient-poor foods (Darmon and Drewnowski, 2015). Low socioeconomic status is a common factor associated with unhealthy eating habits, low fitness levels, and disability among older adults in urban or rural areas (Shahar *et al.*, 2019).

The usage of Linear Programming assists in the development of healthy menus at minimal cost and solves the nutritional problems of older adults with low socioeconomic status (Gazan *et al.*, 2018) and various dietary problems (van Dooren, 2018). Beyond menu development, such models have the potential to guide food assistance programs and inform public health policy by establishing the minimum daily food expenditure required for nutritional adequacy. A cross-sectional study used Linear Programming to create cost-effective, balanced menus aligned with dietary guidelines for cancer prevention, involving 100 adults from a university in Kuala Lumpur (Alaini *et al.*, 2019). The optimized menus met nutrient recommendations while minimizing cost and offering practical solutions for promoting healthy food choices, particularly among low-income groups. Studies are scarce on producing balanced menus for the elderly, especially in Malaysia. Thus, this study has developed healthy menus at a minimum cost for older adults in Selangor using the Diet Optimization Model that meets recommendations from Recommended Nutrient Intake for Malaysia (Ministry of Health Malaysia., 2017). The findings may contribute to more affordable dietary planning, reduce inequities in food access, and support successful ageing in Malaysia and similar contexts.

Materials and Methods

Study design and sampling

This study used the Long Term Research Grant Scheme-Towards Useful Ageing study (LRGS-TUA) data, which prospectively investigates the cognitive decline and its risk factors through a comprehensive multidimensional assessment. It comprises biophysical health, auditory and visual functions, nutrition and dietary patterns, and psychosocial aspects (Shahar *et al.*, 2016). There are several phases of a follow-up study in LRGS after the baseline study (Phase I), namely at 18 months (Phase II), at 36 months (Phase III), and in the sixth year (Phase IV). This was a cross-sectional study using data from respondents in Phase IV. Data was collected using purposive sampling, with sample size calculated based on the previous reference (Cochran, 1977) , and mean value adapted from a local study (Ng *et al.*, 2015). Over 70% of the older adults in Selangor live below the poverty line (Department of Statistics Malaysia DOSM, 2020), limiting their ability to follow dietary recommendations such as RNI 2017

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(Ministry of Health Malaysia., 2017). This is the justification for selecting this state for data analysis. A total of 246 older adults aged 60 years from 10 areas in Selangor, Malaysia, such as Batu 9 Cheras, Kajang, Petaling Jaya, Rasa, Sekinchan, Sungai Pelek, Klang, Taman Keramat, Tanjung Karang, and Tanjung Sepat.

Inclusion and exclusion criteria

Eligible participants were Malaysian older adults aged 60 years and above who were permanent residents of the selected areas and had completed the Diet History Questionnaire (DHQ). Exclusion criteria included bedridden individuals, those diagnosed with psychiatric disorders, or those with significant speech or hearing impairments, as these conditions could compromise data reliability.

Evaluation of under and over-reporting

Respondents' average energy intake was classified according to percentile and categorized as under-reporter with energy intake below 2.5 percentile or over-reporter with energy intake above 97.5 percentile (Fakhruddin *et al.*, 2019, Konstantinova *et al.*, 2008). Based on this guideline, 13 of 246 respondents were excluded from the food intake analysis according to gender.

Diet optimization model using linear programming

A cost-effective, nutritious menu was developed using a Diet Optimization Model via Linear and Non-Linear Programming. Food costs and nutrient compositions were sourced from the National Goods Price Council and Ministry of Domestic Trade and Consumer Affairs (KPDNHEP), Malaysia. Consequently, they analyzed using Microsoft Excel (Microsoft Inc, United States of America) software with the OpenSolver plug-in (Mason, 2012). The basic formulation of the diet optimization model is as follows:

Minimize: $z = \sum cjxj$

Subject to: $bi \leq \sum aij\ xj \leq bi$ and $xj \geq 0$

The amount of food item *j* is represented by *xj; aij* denotes the amount of nutrient *i* in one portion of food item *j; cj* is the cost of a portion of food item *j; bi* represents the largest or smallest acceptable quantity of nutrient *i* (Alaini *et al.*, 2019, Rajikan *et al.*, 2017). The constraints in the model for the study were nutrients' lower level (LL) and tolerable upper intake level (UL) of RNI 2017 (Ministry of Health Malaysia., 2017) and portion size restrictions to ensure palatable, practical and culturally acceptability of menus. The final outputs were cost-minimized diet plans that adhered to all nutrient and portion size requirements.

Ethical considerations

Ethical approval was obtained from Universiti Kebangsaan Malaysia (UKM 1.5.3.5/244/NN-060-2013), and informed consent was obtained.

Data analysis

Data were analyzed using SPSS version 25.0 (IBM, USA). Dietary intake and nutrient composition were assessed using Nutritionist PRO™ version 4.0.0 (Axxya Systems LLC, USA). Gender differences were assessed using independent t-tests for normally distributed variables and the Mann-Whitney U test for non-normally distributed variables. Categorical variables were compared using the chi-square test. Normality of continuous variables was examined through Kolmogorov-Smirnov, skewness, kurtosis, histograms, boxplots, and quantile-quantile plots. Categorical data were reported as frequencies/ percentages, while continuous data were expressed as mean ± SD. A significance level of P-value<0.05 was applied.

Results

Table 1 presents the demographic characteristics of the 246 older adults (60+) in this study, comprising 43.1% men and 56.9% women. Significant gender differences ($P<0.05$) were found in age, education, marital status, occupation, and living arrangements. Men were older on average (73.4 vs. 71.7 years), and more men (19.0%) than women (7.5%) were 80+. Secondary school was the highest education level (39.4%), with more men attaining higher education (19.8% vs. 6.4%). Most were married (72.4%) and unemployed/housewives (55.7%). The average income was RM2,097.98, with men earning significantly more ($P<0.05$). Based on the 2019 poverty line, 71.5% were classified as poor, with a higher prevalence among women (76.4% vs. 65.1%).

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Table 1. Sociodemographic characteristics of the respondents.

Sociodemographic characteristics	Male	Female	Total	P-value[a]
Age (year)	73.3 ± 5.6[b]	71.7 ± 5.2	72.4 ± 5.4	0.021
Age group (year)				
60-69	31 (29.2)[c]	61 (43.6)	92 (37.4)	0.014
70-79	56 (52.8)	68 (48.6)	124 (50.4)	
80≤	19 (17.9)	11 (7.9)	30 (12.2)	
Gender	106 (43.1)	140 (56.9)	246 (100.0)	0.03
Race				
Malay	37 (34.9)	47 (33.6)	84 (34.1)	0.088
Chinese	46 (43.4)	76 (54.3)	122 (49.6)	
Indian	23 (21.7)	17 (12.1)	40 (16.3)	
Education level				
No school	5 (4.7)	33 (23.6)	38 (15.4)	<0.001
Primary school	37 (34.9)	44 (31.4)	81 (32.9)	
Secondary school	43 (40.6)	54 (38.6)	97 (39.4)	
University/college	21 (19.8)	9 (6.4)	30 (12.2)	
Marital status				
Single	1 (0.9)	4 (2.9)	5 (2.0)	<0.001
Marriage	95 (89.6)	83 (59.3)	178 (72.4)	
Separated/divorced	1 (0.9)	3 (2.1)	4 (1.6)	
Widow/widower	9 (8.5)	50 (35.7)	59 (24.0)	
Living arrangement				
Alone	1 (0.9)	15 (10.7)	16 (6.5)	0.01
With husband/wife	32 (30.2)	31 (22.1)	63 (25.6)	
With husband/wife, children/ grandchildren	69 (65.1)	86 (61.4)	155 (63.0)	
Others	4 (3.8)	8 (5.7)	12 (4.9)	
Occupation				
Not working/housewives	42 (39.6)	95 (67.9)	137 (55.7)	<0.001
Pensioner	51 (48.1)	35 (25.0)	86 (35.0)	
Pensioner but still working	3 (2.8)	2 (1.4)	5 (2.0)	
Working	10 (9.4)	8 (5.7)	18 (7.3)	
Household income (RM)	2572.64 ±3488.96	1738.59 ± 1893.88	2097.98 ±2724.55	0.019
Household income category base on PGK[d]				
< RM2208	69 (65.1)	107 (76.4)	176 (71.5)	0.011
RM2209 - RM4849	26 (24.5)	19 (13.6)	45 (18.3)	
RM4850 - RM10959	7 (6.6)	14 (10.0)	21 (8.5)	
RM10960<	4 (3.8)	0 (0.0)	4 (1.6)	

[a]: Chi-square test used for qualitylitative and Mann-Whitney U test used for quantitative variables; [b]: Mean±SD; [c]: n(%); [d]: Source: Department of Statistics Malaysia (2020).

Table 2 presents respondents' anthropometric measurements. Men had significantly higher weight (68.1±12.4 kg) and height (163.4±5.6 cm) than women (59.0±10.7 kg, 150.6±5.2 cm) (P<0.001), while women had higher body fat (38.4±7.6%) than men (26.0±5.2%) (P<0.05). **Figure 1** shows the prevalence of body mass index (BMI) classification of older adults by gender. Mean BMI was 24.4±4.0 kg/m² (men) and 26.1±4.9 kg/m² (women), with no significant gender difference. Based on the WHO (2004) classification, the prevalence of underweight, normal weight, overweight, obese class I, obese class II, and obese class III among the elderly in Selangor was 3.7%, 43.1%, 38.6%, 10.6%, 3.3%, and 0.8% respectively. Females showed a higher prevalence of obesity categories, emphasizing the need for targeted interventions.

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Table 2. Anthropometric measurements.

Anthropometric measurements	Male (N=106)	Female (N=140)	Total (N=246)	P-value[a]
Weight (kg)	68.1 ± 12.4[b]	59.0 ± 10.7	62.9 ± 12.3	0.001
Height (cm)	163.4 ± 5.6	150.6 ± 5.2	156.6 ± 8.7	0.001
Body mass index (kg/m^2)	24.4 ± 4.0	26.1 ± 4.9	25.7 ± 4.5	0.095
Body fat (%)	26.0 ± 5.2	38.4 ± 7.6	33.1 ± 9.1	0.001
Categories of body mass index				
Underweight	5 (4.7)[c]	4 (2.9)	9 (3.7)	0.502
Normal weight	49 (46.2)	57 (40.7)	106 (43.1)	
Overweight	41 (38.7)	54 (38.6)	95 (38.6)	
Obese class I	9 (8.5)	17 (12.1)	26 (10.6)	
Obese class II	2 (1.9)	6 (4.3)	8 (3.3)	
Obese class III	-	2 (1.4)	2 (0.8)	

[a] *independent t-test;* [b]*: Mean±SD;* [c]*: n(%).*

Table 3 compares nutrient intake between genders. Men's energy intake (1600±250 kcal/day) was significantly higher than women's (1416±262 kcal/day) (*P*<0.05), meeting 78.8% and 80.0% of the recommended intake, respectively. Both met the RNI 2017 protein recommendation. Carbohydrates contributed most to energy intake (52% men, 53% women). Moreover, fat intake exceeded the 30% UL, with men at 31.8% and women at 31.2%. Men had significantly higher carbohydrate, fat, and protein intake than women (*P*<0.005). Moreover, there were significant gender differences (*P*<0.05) in thiamine, riboflavin, niacin, and calcium intake. Only vitamin A, C, iron, and phosphorus met nutrient recommendations. Thiamine intake was higher in men (0.7±0.3 mg) than in women (0.6±0.2 mg), while riboflavin intake was lower in women (0.9±0.3 mg) than in men (1.0±0.3 mg). Niacin and riboflavin intake were inadequate. Fibre intake exceeded minimum recommendations, but sodium intake surpassed the UL (2300 mg/day) for both genders.

Table 3. Comparison of daily nutrient intake by gender.

Nutrients	Male (n = 100)	RNI	% RNI	Female (n = 133)	RNI	% RNI
Energy (kcal)	1600 ± 250 [b]	1780	78.8 ± 12.3	1416 ± 262	1550	80.0 ± 14.8[a]
Protein (g)	63.8 ± 14.7 [b]	58.0	110.1 ± 25.4	57.6 ± 14.3	50.0	115.3 ± 28.7
Carbohydrate (g)	208.6 ± 44.6 [b]	-	-	185.6 ± 42.2	-	-
Fat (g)	56.4 ± 12.8 [b]	-	-	49.1 ± 13.2	-	-
Fibre (g)	5.6 ± 3.7	30.0	18.7 ± 12.4	5.5 ± 4.1	25.0	22.1 ± 16.3
Vitamin A (RE)	649.1 ± 288.2	600.0	108.2 ± 48.0	615.6 ± 239.1	600.0	102.6 ± 39.8
Vitamin C (mg)	98.3 ± 54.9	70.0	140.4 ± 78.4	98.6 ± 55.6	70.0	140.8 ± 79.5
Thiamine (mg)	0.7 ± 0.3 [b]	1.2	58.8 ± 20.5	0.6 ± 0.2	1.1	56.8 ± 17.0
Riboflavin (mg)	1.0 ± 0.3[c]	1.3	77.1 ± 23.9	0.9 ± 0.3	1.1	77.3 ± 23.2
Niacin (mg)	9.4 ± 2.7 [c]	16.0	58.8 ± 16.7	8.0 ± 2.4	16.0	58.9 ± 17.0
Sodium (mg)	2590.5 ± 1054.4	1200.0	172.7 ± 70.3	2333.1 ± 675.8	1200.0	155.5 ± 45.1
Potassium (mg)	1326.7 ± 335.4	4700.0	28.2 ± 7.1	1200.2 ± 335.2	4700.0	25.5 ± 7.1
Calcium (mg)	394.7 ± 193.7 [b]	1000.0	39.5 ± 19.4	341.5 ± 146.0	1200.0	28.5 ± 12.2
Iron (mg)	19.4 ± 43.3	14.0	129.1 ± 68.8	14.2 ± 7.6	11.0	138.5 ± 309.0
Phosphorus (mg)	816.6 ± 216.4	700.0	116.7 ± 30.9	754.5 ± 209.8	700.0	107.8 ± 30.0

[a] *Mean±SD;* [b]*: Significant differences (P<0.05) between males and females according to the independent t-test;* [c]*: Significant differences (P<0.05) between males and females according to the Mann-Whitney U test.*

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Table 4 presents two optimized menus designed for older adults based on energy requirements of 1800 kcal and 2000 kcal per day which met LL and a UL of nutrient constraints from RNI 2017. For the 1800 kcal model, the daily menu included practical and culturally familiar foods such as fried rice with fish and vegetables, porridge, brown rice meals with chicken or sardine dishes, bananas, guava juice, and milk. The 2000 kcal model incorporated slightly larger portions and additional items, such as grilled fish, soybean milk, and an extra evening milk serving. Despite their differences, both menus demonstrated variety across food groups (grains, animal protein, vegetables, fruits, and dairy), ensuring a balanced diet. Importantly, the cost of the menus was kept low, namely RM8.00 per day for 1800 kcal and RM8.69 per day for 2000 kcal, making them affordable for older adults living below the poverty line.

Table 5 compares the nutritional information of two menus based on different caloric intake. Both the 1800 kcal and 2000 kcal menus met recommended nutrient requirements. Macronutrient distribution was balanced (protein 19%, fat 22 to 26%, carbohydrate 55 to 60%), fibre intake reached the daily target, and sodium remained below the upper limit. All key micronutrients, including calcium, iron, potassium, and vitamins, were within recommended ranges, confirming the menus' nutritional adequacy at minimal cost. Overall, **Table 5** demonstrates that the optimization model produced menus that are nutritionally adequate across all key nutrients while keeping costs low. This highlights the potential of the model to design diets that are both affordable and aligned with national dietary recommendations for older adults.

Table 4. Development of two menus according to caloric intake (1800 and 2000 kcal).

Caloric intake (kcal/day)	1800 kcal	2000 kcal
Meal	Model 1	Model 2
Breakfast	▪ Fried rice with yellowtail scad fillet, spinach and mustard greens (1 plate) ▪ Guava juice (1 glass)	▪ Brown rice chicken porridge (2 cups) ▪ Ladyfinger banana "*Pisang mas*" (2 pieces)
Morning snack	▪ *Omega Plus* powder milk (2 tablespoons) ▪ Lady finger banana "*Pisang mas*" (2 pieces)	▪ Wholegrain bread (1 piece) ▪ *Omega Plus* powder milk (2 sudu makan) ▪ Ladyfinger banana "*Pisang mas*" (2 pieces)
Lunch	▪ Brown rice (2 cups) ▪ Steamed chicken with potatoes (1 piece) ▪ Mixed vegetables with a chicken cube, spinach and mustard greens (1 cup)	▪ Brown rice (1 ½ cup) ▪ Grilled torpedo scad "*cencaru*" + chilly soy sauce gravy (½ piece M size) ▪ Vegetable soup with spinach, green mustard and potatoes (1 cup) ▪ Guava juice (1 glass)
Afternoon snack	▪ *Everyday* powder milk (4 tablespoons)	▪ Soybean milk (1 glass)
Dinner	▪ Brown rice (1½ cup) ▪ Sardine+red bean curry with coconut milk (1 cup) ▪ Mixed vegetables with a chicken cube, spinach and mustard greens (1 cup) ▪ Ladyfinger banana "*Pisang mas*" (2 pieces)	▪ Brown rice (1 cup) ▪ Fried yellowtail scad (1 piece) ▪ Vegetable soup with spinach, green mustard and potatoes (1 cup) ▪ Ladyfinger banana "*Pisang mas*" (2 pieces)
Supper	▪ Nil	▪ *Everyday* powder milk (3 tablespoons)
Food cost per day (RM)	▪ RM8.00	▪ RM8.69

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Table 5. Nutritional information of two menus based on different caloric intake (1800 and 2000 kcal).

Variables	1800 kcal			2000 kcal		
	Lower level	Tolerable upper intake level	Consumption	Lower level	Tolerable upper intake level	Consumption
Macronutrients						
Energy (kcal)	1500	1800	1790	1800	2200	2045
Protein (g)	10%	20%	83.37 (19%)	10%	20%	95.3 (19%)
Fat (g)	20%	30%	43.49 (22%)	20%	30%	59.4 (26%)
Carbohydrates (g)	50%	65%	266.95 (60%)	50%	65%	383.7 (55%)
Micronutrients						
Calcium (mg)	1000	2000	1403.75	1000	2000	1339.5
Iron (mg)	11	45	20.7	14	45	25.5
Phosphorus (mg)	700	4000	1147.33	700	4000	1344.9
Potassium (mg)	4700	10000	4843.55	4700	10000	4726.7
Sodium (mg)	0	2300	1562.51	0	2300	2172.6
Vitamin C	70	2000	292.3	70	2000	321.6
Thiamine (mg)	1.2	500	1.27	1.2	500	1.6
Riboflavin (mg)	1.3	23	1.84	1.3	23	2.5
Niacin (mg)	16	35	16.12	16	35	16
Vitamin A (µRE)	600	3000	1909.25	600	3000	2183.3
Fibre (g)	25	50	25.17	30	50	30.6

Discussion

This study developed a cost-effective healthy menu for older adults in Selangor using the Diet Optimization Model based on RNI 2017. Findings show that 71.5% of older adults live below the national poverty line (Department of Statistics Malaysia DOSM, 2020). Studies indicate that the lower-income elderly have a higher risk of food insecurity than the PGK (Mesbah *et al.*, 2018). The study in rural areas, namely, the agricultural resettlement FELDA Lubuk Merbau, Kedah, found that one-third of respondents suffered from underweight, depression, and stress from family and food insecurity (Saleh Hudin *et al.*, 2017). Developed countries such as Europe have reported that household income and employment are the two main contributors to food insecurity for those aged 50 and above (Nie and Sousa-poza, 2017). The study in Mexico reported that food insecurity was associated with frailty, and this condition puts the elderly at a higher risk of developing adverse health outcomes (Perez-Zepeda *et al.*, 2016).

The older women (38.4±7.6%) have a higher body fat percentage than older men. Similarly, other studies also found body fat percentage for older women in Kuala Lumpur and Selangor was unhealthy (35.1±5.2%) (Leiu *et al.*, 2020). Aging is associated with several physiological, psychological, and biological changes, including body composition, such as increased body fat and decreased lean and bone mass (Santoro *et al.*, 2018). A total of 3.7% of older adults are underweight, which is lower than the prevalence reported by the National Health and Mobility Survey (2018), which is 5.2%. On the other hand, the percentage of overweight people was 38.6%, more than 37.0%, as reported by the National Health and Mobility Survey 2018 (Institute for Public Health, 2018). Both underweight and overweight are associated with increased risks of poor health and mortality (Selvamani and Singh, 2018). The potential risk of being overweight and obese is the development of chronic diseases such as heart disease, which is a leading cause of mortality in older adults (Keramat *et al.*, 2021).

Energy intake for both men and women in the elderly did not meet the RNI 2017 (Ministry of Health Malaysia, 2017). However, the prevalence of overweight and obesity in this study shows the opposite outcome. This finding may be due to less reported energy intake than actual intake during food intake assessment. Misreporting of dietary

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intake is a well-documented problem across population groups (Banna *et al.*, 2017). Protein intake for both genders has successfully met the RNI (2017) recommendation. Furthermore, a study conducted at the elderly care institution of Rumah Seri Kenangan in Selangor reported a higher energy and protein intake among older men than older women (Fatin-Izzaty and Noraida, 2018).

This study found that the intake of fibre, thiamine, riboflavin, niacin, potassium, and calcium did not meet the recommendations. The inadequate thiamin intake was related to improper rice milling processes and the consumption of polished rice (Johnson *et al.*, 2019). In contrast, low riboflavin intake was due to a lack of food sources providing significant amounts of this vitamin (Titcomb and Tanumihardjo, 2019). Foods rich in riboflavin are milk, green vegetables, meat, and the internal organs of animals and legumes (Pinto and Zempleni, 2016), and niacin is high in tuna anchovies, whole grains, legumes, and mushrooms (Kirkland and Meyer-Ficca, 2018). Low thiamine or vitamin B1 intake is associated with dementia among the elderly (Gibson *et al.*, 2016).

The NHMS reported that the percentage of older adults who met the recommendation of two or more servings of fruits daily was 10.8%. The percentage of older adults who met three or more servings of vegetables daily was 10.9% (Institute for Public Health, 2019). Similar findings were obtained for this study, where older men consume only 5.6±3.7 grams of fibre less than the minimum recommended RNI 2017, which is 30 grams daily. Olderwomen only consume 5.5±4.1 grams of fiber compared to the minimum recommended 25.0 grams per day. Sodium intake has met the recommendation, where men take 2590.5±1054.4 mg, and women take 2333.1 ± 675.8 mg, but have exceeded the maximum sodium UL of 2300 mg per day. Sodium is an important micronutrient for cell homeostasis and the body's physiological functions. However, excessive sodium intake from the diet is associated with increased blood pressure (Farquhar *et al.*, 2015).

The price list of food items obtained from the National Price Council, Ministry of Domestic Trade and Consumer Affairs (KPDNHEP) is required for the development of a healthy and balanced diet model at minimum cost using the Diet Optimization Model through Mathematical Programming (Alaini *et al.*, 2019, Rajikan *et al.*, 2017). The food obtained is the average price in Selangor from January to March 2020. This month was chosen because it is the latest price of raw materials for the year 2020 obtained from KPDNHEP before the government announced the Movement Control Order (MCO) due to the COVID-19 pandemic crisis in Malaysia on 18th March 2020. Studies show that during the COVID-19 pandemic, there was a surge of high demand for food due to panic buying and stocking of food at home, which caused the price of goods to rise sharply (Hobbs, 2020, Nicola *et al.*, 2020).

The Mathematical Programming successfully created two diet optimization models that met the LL and UL of nutrient constraints from RNI 2017. The minimum cost for the 1800 kcal model is RM8.00 and RM8.69 for the 2000 kcal model, as shown in **Table 4**. A previous study has demonstrated that Linear Programming has estimated the minimum food cost to be RM6.55 for a total energy intake of 2000 kcal per day for low socioeconomic female adults in Malaysia (Rajikan *et al.*, 2017). A study conducted by Alaini *et al*. produce a menu of cancer prevention for selected adult populations in Kuala Lumpur found that using Linear Programming for energy needs 1800 kcal per day and 1900 kcal per day generated minimum costs of RM7.80 and RM9.70 (Alaini *et al.*, 2019). This study's findings show that the cost of 2000 kcal per day produced is lower than that of Alaini *et al*.. Looking at the Consumer Price Index (CPI) report in March 2020, it was found that the index had decreased by 0.2% to 120.9% compared to 121.1% in the same month of 2019 (Department of Statistics Malaysia, 2020).

Selection of a menu with a soft texture, such as porridge, is considered during the development of the menu due to physiological changes that make it difficult for older adults to swallow and have

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difficulty biting food due to a lack of teeth (Cichero, 2018). Therefore, food with changes in texture is suitable for older adults who suffer from this problem because it has a softer texture (Cichero, 2016) 2016). **Table 4** shows the nutritional information of two menus based on different caloric intakes. Menu recommendations for the elderly in this study limit sodium between 1200-2300 milligrams of salt. The two healthy menus use a minimum of 1 tablespoon of oil, and as alternatives to the fried menu, other cooking styles such as steaming, grilling, and soup are recommended in the menu. A past study shows that healthy cooking methods, such as steaming, can reduce fat content in food (Asmaa *et al.*, 2015).

This study has some limitations. It relies on secondary data, making it vulnerable to methodological errors. Limited food availability restricts fiber, potassium, and niacin intake. The Malaysian food composition database (Tee *et al.*, 1997) lacks key nutrients like vitamins D, E, and folate (Fakhruddin *et al.*, 2019), affecting diet optimization accuracy. This study relied on purposive sampling of 246 older adults from 10 areas in Selangor, which may not fully represent older populations in other states or cultural settings. As a result, the findings may have limited generalizability beyond the study locations. Next, the optimized menus were not tested for taste, cultural acceptability, or adherence. Nutritional adequacy and low cost alone may not ensure adoption by older adults. Factors such as personal food preferences, traditional dietary practices, chewing or swallowing difficulties, and convenience strongly influence acceptance in aging populations (Cichero, 2016). Future studies should include sensory testing and feasibility trials to assess real-world applicability. Despite several constraints, this study demonstrates that mathematical diet optimization can generate nutritionally adequate menus at low cost, providing valuable insights for food policy, welfare programs, and healthcare providers.

Conclusion

Older adults in Selangor have an average household income below the Poverty Line Income (PGK). Most are overweight, obese, and have high body fat. While their intake of vitamin A, C, iron, and phosphorus meets RNI 2017, their sodium intake exceeds UL recommendations. The Diet Optimization Model identified minimum food costs (RM8.69 for older adults, RM8.00 for senior citizens) and successfully designed cost-effective, healthy menus for 1800 kcal and 2000 kcal based on RNI 2017. The integration of affordability into dietary planning has the potential to reduce nutrition inequities and support healthy ageing in Malaysia.

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Authors' contributions

All authors contributed equally to the study's conception, design, data analysis, and writing of the original draft. Sudin S, Rrajikan R and Yahya HM led data collection. Sudin S arranged funding acquisition. Shahar S wrote the original draft. Rrajikan R, Shahar S, Yaacob N, Muniandy S and Elias SM were reviewed and edited. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declared no competing interests.

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