Integer and Goal Programming Techniques for Highlighting Nutritional Menu in Malaysian Teenagers with Chinese Herbal Food

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ABSTRACT

In Malaysia, the rise in noncommunicable diseases (NCDs) disease among teenagers highlights the urgent need for improved dietary planning. Frequent consumption of fast foods and sugary beverages, such as milk tea, which put them at a higher risk of diabetes, hypertension, and heart disease among this age group. Integrating Chinese herbal foods and supplements into their diet, drawing inspiration from traditional Chinese medicine (TCM), provides a potential strategy to enhance teenager's overall health and prevent diseases. This study aimed to design a five-day menu for Malaysian teenagers aged 20 to 29, divided into males (20-24) and females (25-29). It focused on determining daily nutrient requirements and identifying the most cost-effective meal options that meet these nutritional needs. Integer Programming and Goal Programming optimization techniques were applied to the menu planning process, with analyses conducted using LPSolve IDE and LINGO software. The Integer Programming model produced menus that fulfil the nutritional requirements at an average daily cost of RM 17.40 for Case 1, and RM 18.70 for Case 2, comprising four meals per day. While Goal Programming provided a near optimal solution, it was found to be less suitable for menu planning. This study explores the potential application of the proposed menu in daily life, workplaces, and hospitals, while highlighting it limitations, such as the lack of consideration for food allergies, the narrow focus on a specific age group, and constraints associated with the LINGO software.

Keywords: Optimization, Menu Planning, Integer Programming, Goal Programming, Chinese Herbal Supplement, Teenager

INTRODUCTION

In Traditional Chinese Medicine (TCM), food seen as both nourishment and medicine, emphasizing balance and holistic well-being. Unlike modern nutrition, Chinese dietary therapy categorizes foods by flavours (spicy, sweet, sour, bitter, and salty) rather than macronutrients. In recent years, TCM gained wider acceptance in Western countries, with over one hundred countries, including the United States and countries in Europe, adopting policies to promote TCM practices. For instance, the World Health Organization reported the widespread use of TCM, with ginseng being a prominent ingredient in dietary supplements [1]. A 2022 study further highlighted the acceptance of Chinese Herbal Medicine (CHM) in the United States, as licensed acupuncturists commonly prescribe it to treat conditions such as COVID-19 symptoms, reflecting its continued demand in healthcare [2].

In Malaysia, TCM coexists alongside mainstream medicine, with herbal treatments deeply rooted in local traditions. Public awareness and acceptance of Chinese Herbal Medicine (CHM) are positive, although differences exist across ethnic and religious groups [3]. However, while research has primarily focused on Chinese herbs for managing specific health conditions, there is limited exploration on incorporating herbal supplements into the diet plans of Malaysia teenagers. A study conducted at the Traditional and Complementary Medicine (T&CM) clinic at Hospital Sultan Ismail, Johor, investigated the top ten herbs used by cancer patients and evaluated their impact on quality of life (QoL) [4].

The National Health and Morbidity Survey conducted in 2019 revealed alarming statistics, 1 in 5 Malaysian adults has diabetes, 1 in 3 has high blood pressure, and nearly half are overweight or obese [5]. These trends extended to teenagers, where rising cases of non-communicable diseases (NCDs) such as diabetes, obesity, and cancer highlighted the need for improved the dietary planning to avoid these health issues.

This study aimed to bridge dietary planning and herbal therapy by adding Chinese herbal supplements into a systematic diet optimization approach. Unlike existing studies that focused solely on herbs for specific diseases or adult populations, this study introduced a holistic menu plan for teenagers, guided by the Recommended Nutrient Intake (RNI) 2017, Malaysian Dietary Guidelines (MDG), recent research, and consultations with dietitians and Chinese herbalist. Three objectives were formulated for this study, which are to determine the daily nutrient requirement for teenagers by data gathering from RNI 2017 and websites, to identify the low-cost meals for two different case studies that would satisfy the nutrient requirement of teenager by using Integer Programming, and to plan a five-day special diet that fulfil the nutrient requirement for teenagers in different categories by using Integer Programming and Goal Programming.

Additionally, the Delete Reshuffle Algorithm ensures a diverse and non-repeating menu over the five days. This research provided a novel contribution to dietary planning by integrating Chinese herbal foods into menu optimization, promoting both health improvement and disease prevention among Malaysian teenagers.

Fig.1 Common Herbs used in Traditional Chinese Herbal Soups

RESEARCH METHODOLOGY

Data Collection

Dietary information for teenagers was obtained from the Recommended Nutrient Intake (RNI) 2017 [6] and the Malaysia Dietary Guidelines (MDG) [7]. Nutrient boundaries were determined based on these references and consultations with a dietitian. The food database for this study was developed using data from the Nutrient Composition of Malaysian Foods [8], to ensure the diet plan meets the nutritional needs of the Malaysian population.

Factors such as seasonality, location, and local supply chains were recognized as potential assumptions influencing food availability and market price variability [9]. As a result, alternative scenarios were considered to manage situations where certain food might be unavailable or experience prices spikes, allowing adjustments to the menu plan.

Additionally, detailed discussions with a dietitian and a Chinese Herbalist provided insights into the nutritional requirements and suitable Chinese herbal foods and supplements for teenagers. These interviews were conducted in a structured format with standardized questions based on evidence from reliable sources.

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Recommendations were cross referenced with peer-reviewed studies to maintain transparency and ensure objectivity in the consultation process.

For this study, a total of 380 food items were selected based on recommendations from the dietitian and Chinese herbalist. These selections were guided by the RNI 2017, MDG, the Nutrient Composition of Malaysia Foods book, and other reliable online sources. The food items were reviewed and validated by the dietitian to ensure accuracy and suitability for the study.

Modelling

The mathematical modelling for planning a diet for teenagers depended on their nutritional requirements and budget constraints. In this research, Integer Programming and Goal Programming were used to design diet menus for male teenagers aged 20 to 24 and female teenagers aged 25 to 29. Each menu included four meals per day over five days.

This study consisted of two types of models: the Small Data Model and the Big Data Model. The Small Data Model included 80 types of food selected from each of the food groups, which were used in the pilot study. The Big Data Model consisted of the full food dataset of 380 food types, which were used in the formal study.

Objective Function

For this study, the objective was to use Integer Programming (IP) and Goal Programming (GP) to choose the foods that could fulfil the nutrients requirements at the minimum cost for teenagers.

The objective function of IP was shown as below [10]:

$$Minimize\ cost = \sum_{i=1}^{N} \sum_{j=1}^{P} \sum_{k=1}^{Q} c_i\, x_{ijk} \quad (1)$$

where

x_{ijk} = Decision variables of food item *i*, food groups *j* and meals *k*

c_i = Cost for each food item *i*

P = Number of food groups

Q = Number of meals per day

N = Total number of food items

The objective function of GP was shown as below [11]:

$$Minimize \quad \sum_{i=1}^{N} (d_i^+ + d_i^-) \quad (2)$$

where

i = the set of nutrients

d_i^-, d_i^+ = the negative and positive deviations from

goal g_i

Constraints of General Nutritional Requirements

The equation of IP was shown as below:

$$LB_i \leq \sum_{i=1}^{N} \sum_{j=1}^{P} \sum_{k=1}^{Q} w_i \, x_{ijk} \leq UB_i \quad (3)$$

The equation of GP was shown as below:

$$\sum_{i=1}^{N} \sum_{j=1}^{P} \sum_{k=1}^{Q} w_i \, x_{ijk} \geq LB_i \quad (4)$$

$$\sum_{i=1}^{N} \sum_{j=1}^{P} \sum_{k=1}^{Q} w_i \, x_{ijk} \leq UB_i \quad (5)$$

where

LB_i	=	Lower bound of nutrients
UB_i	=	Upper bound of nutrients
w_i	=	Weight of each nutrient of the food

In this study, ten types of nutrients were involved, namely energy, protein, fats, carbohydrate, vitamin B9, vitamin B12, vitamin C, vitamin D, calcium, and iron. The standard daily requirements for these ten nutrients for teenagers were obtained from the RNI 2017. There were different nutrients boundaries across the two case studies.

Case 1 involved a 22-year-old male undergraduate with an unhealthy lifestyle, which include avoiding sports and staying up late. His height and weight are 178 cm and 70 kg.

Case 2 involved a 26-year-old female florist who led a healthy lifestyle, typically sleeping before midnight. She is 173 cm tall, weighs 68 kg, and experiences menstrual disorders, dizziness, and insufficient nutrient intake. The suggested nutrient intake for both case studies, with its lower and upper bounds, was mentioned in Chapter 3: Results and Discussion.

Constraints of Food Group Requirements

The second constraint in this study focused on general food group requirements for teenagers aged 20 to 29. The meal plan, which included breakfast, lunch, dinner, and supper, totaling 15 dishes per day from 8 food groups.

The constraint of food group requirements was shown below:

$$\sum_{i=1}^{8} Type\ of\ food\ group\ (x_i) = n \quad (6)$$

(6)

where

x_i = Decision variables of food items

= Number of dishes

RESULT AND DISCUSSION

This chapter discussed diet plans designed for two teenagers (Case 1 and Case 2) to improve their health at minimal cost. The menus were developed using Integer Programming (IP) and Goal Programming (GP), with the Delete-Reshuffle Algorithm applied to ensure the diet plan fulfils the teenagers' specific dietary needs while increasing food variety.

A dataset of 380 decision variables based on Nutrient Composition of Malaysian Foods was used to ensure a diverse selection of food items. Chinese herbal supplements, such as dried wolfberries, red dates, and dried longan, were incorporated into the lunch menu to meet the unique health needs for teenagers. To better manage calorie intake, particularly during supper, miscellaneous items were replaced with dry roasted walnuts, providing nutritional balance.

Goal programming, a flexible method for balancing the nutrient requirements with multiple objectives, such as minimizing cost or achieving a balanced diet, was applied in two scenarios. In the first scenario, both cost and nutrient were treated as soft constraints. In the second scenario, cost was treated as hard constraints and nutrients as soft constraints [12]. Both scenarios provided feasible solutions, with the second scenario selected as the most suitable and adopted in this study.

All the menus were generated using IP on LPSolve IDE and GP on LINGO. The constraints included nutrient and food group requirements, ensuring the menu for both cases met these necessary dietary conditions. Each daily menu consisted of breakfast, lunch, dinner, and supper.

Case 1

For Case 1, the menu included a variety of food groups, such as beverages, cereals, fruits, vegetables, meat, seafood, miscellaneous items, and Chinese herbal supplements including dried wolfberries, dried longan, and red dates. Meat dishes, such as cordyceps flower chicken soup and ginseng herbal soup, were included to enhance both the flavour and health benefits of the meals.

Table 1 and 2 present the five-day menu plan for teenagers. The availability of nutritious local foods in every meal promoted healthier eating habits among teenagers. From Table 1, the menu cost increases slightly from RM 15.50 to RM 20.10. Similarly, Table 2 shows a rising from RM 18.20 to RM 25.10.

The results of this study have significant implications for public health in Malaysia. Optimized menu plans for teenagers, incorporating local food items and Chinese herbal supplements, can help manage issues such as malnutrition, obesity, and iron deficiency among Malaysian adolescents [13]. By promoting balanced diets that meet nutritional requirements, this approach can help improve overall adolescent health and reduce long-term healthcare costs related to diet-related diseases [14].

Table 1: 5 days for Case 1 using Integer Programming

Meal	Day 1	Day 2	Day 3	Day 4	Day 5
Breakfast	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]
	Biscuit, coconut [1]	Biscuit, finger cream [1]	Biscuit, soda/ plain [1]	Putu bambu [1]	Biscuit, marie [1]
	Nangka [1]	Guava [1]	Kismis [1]	Papaya [1]	Rambutan [1]
Lunch	Sugar cane	Milo [1]	Coconut	Lengkong [1]	Limau only [1]

	juice [1]		water [1]		
	Rice, cooked [1]	Char siew rice [1]	Rice, coconut milk [1]	Rice, fried [1]	Rice, chicken [1]
	Cordyceps flower chicken soup [1]	Satay only [1]	Chicken satay [1]	Ginseng herbal chicken soup [1]	Quail egg, whole [1]
	Spinach (bayam pasir) [1]	Asparagus canned [1]	Mustard leaves, Chinese [1]	Mengkudu [1]	Celery (daun seladeri) [1]
	Wolfberry, dried [1]	Red date [1]	Longan, dried [1]	Wolfberry, dried [1]	Red date [1]
Dinner	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]
	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]
	Indian mackerel, fried in chilli [1]	Fish unspecified, dried, salt [1]	Sambal udang [1]	Tuna, cooked in coconut milk [1]	Fish satay snack [1]
	Spinach (bayam pasir) [1]	Spinach (bayam duri) [1]	Mustard leaves, Chinese [1]	Mengkudu [1]	Celery (daun seladeri) [1]
	Nangka [1]	Guava [1]	Kismis [1]	Papaya [1]	Cempedak [1]
Supper	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]
	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]
Cost (RM)	19.20	15.50	16.10	20.10	16.10

Table 2: 5 days for Case 1 using Goal Programming

Meal	Day 1	Day 2	Day 3	Day 4	Day 5
Breakfast	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]
	Oats, processed, tinned [1]	Dumpling sang yoke [1]	Dumpling char siew [1]	Dumpling, big [1]	Dosai with egg [1]
	Apple, green [1]	Rambai [1]	Kismis [1]	Pineapple [1]	Pear yellow [1]
Lunch	Milo [1]	Milk, sterilised [1]	Yoghurt, apricot flavour [1]	Yogurt banana [1]	Apple juice [1]

	Rice, fried [1]	Nasi briyani (rice only) [1]	Rice, chicken [1]	Rice, cooked [1]	Rice, "dagang" [1]
	Quail egg, whole [1]	Satay only [1]	Cordyceps flower chicken soup [1]	Sausage, chinese [1]	Ginseng herbal chicken soup [1]
	Lady's fingers [1]	Lettuce [1]	Mung bean [1]	Bean, French [1]	Bean, string [1]
	Wolfberry, dried [1]	Red date [1]	Longan, dried [1]	Wolfberry, dried [1]	Red date [1]
Dinner	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]
	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]
	Spanish mackerel, fried (Ikan tenggiri goreng) [1]	Threadfin bream, in soya sauce (Ikan kerisi masak kicap) [1]	African bream, fried in chili [1]	Sardine, canned [1]	Anchovy, dried, fried in chilli [1]
	Petai [1]	Radish, chinese [1]	Soya bean sprout [1]	Mushroom, Chinese, dried [1]	Mushroom, grey oyster, fresh [1]
	Apple, green [1]	Rambai [1]	Kismis [1]	Pineapple only [1]	Pear yellow [1]
Supper	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]
	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]
Cost (RM)	18.70	18.20	22.60	18.50	25.10

Case 2

For Case 2, the menu includes all essential food groups, such as beverage, cereals, fruits, iron-rich vegetables, meat, seafood, miscellaneous items, and Chinese herbal supplements. Iron-rich vegetables, such as spinach, mustard leaves, and broccoli are specifically added to support the iron requirements of female teenagers. Furthermore, the menu features food items with lower macronutrient values compared to the Case 1 menu, catering to the specific dietary needs of the teenager in this case. From Table 3, the total cost of preparing the menu increases from RM 16.20 to RM 20.60. Similarly, Table 4 shows a rise in total cost, increasing from RM 16.70 to RM 23.80.

Iron deficiency remains a significant health issue globally, particularly among women. In Malaysia, iron deficiency anaemia is prevalent among female teenagers, leading to fatigue and weakness. Including iron-rich foods such as dried fruits, almonds, and spinach in the diet is a cost-effective strategy to solve this issue [15].

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Table 3: 5 days for Case 2 using Integer Programming

Meal	Day 1	Day 2	Day 3	Day 4	Day 5
Breakfast	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]
	Biscuit, finger cream [1]	Biscuit, coconut [1]	Cookies oats [1]	Biscuit soda/ plain [1]	Cookies, peanuts [1]
	Guava [1]	Banana, common varieties [1]	Kismis [1]	Papaya [1]	Grape [1]
Lunch	Milo [1]	Lengkong [1]	Limau only [1]	Coconut water [1]	Sarsi [1]
	Rice, cooked [1]	Rice, chicken [1]	Rice, briyani (rice only) [1]	Rice, fried [1]	Rice, porridge, fish, instant [1]
	Cordyceps flower chicken soup [1]	Quail egg, whole [1]	Hen egg, whole [1]	Ginseng herbal chicken soup [1]	Maw satay [1]
	Asparagus, cannned [1]	Spinach onion (daun bawang) [1]	Asam gelugor, pucuk [1]	Broccoli [1]	Petai [1]
	Wolfberry, dried [1]	Red date [1]	Longan, dried [1]	Wolfberry, dried [1]	Red date [1]
Dinner	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]
	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]
	Indian mackerel, fried in chilli [1]	Fish unspecified, dried, salt [1]	Sambal udang [1]	Tuna, cooked in coconut milk [1]	Fish satay snack [1]
	Spinach (bayam pasir) [1]	Spinach (bayam duri) [1]	Mustard leaves, Chinese [1]	Mengkudu [1]	Tomato juice, canned [1]
	Nangka [1]	Guava [1]	Kismis [1]	Papaya [1]	Watermelon [1]
Supper	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]
	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]
Cost (RM)	19.30	16.20	17.50	20.60	19.90

Table 4: 5 days for Case 2 using Goal Programming

Meal	Day 1	Day 2	Day 3	Day 4	Day 5
Breakfast	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]	Milk, cow, fresh [1]
	Biscuit savoury [1]	Oats, processed, tinned [1]	Bread, white [1]	Biscuit, cream crackers [1]	Biscuit, alphabet [1]
	Kiwi [1]	Nangka [1]	Cashew apple (jambus gajus) [1]	Cempedak [1]	Banana (pisang tanduk) [1]
Lunch	Milk powder, skim [1]	Orange flavoured drink, powder [1]	Malted milk drink, powder [1]	Coffee powder, instant [1]	Milk, sterilised [1]
	Nasi beriyani [1]	Chicken rice [1]	Nasi briyani (rice only) [1]	Char siew rice [1]	Rice, chicken [1]
	Sausage, Chinese [1]	Satay only [1]	Cordyceps flower chicken soup [1]	Rendang hati [1]	Ginseng herbal chicken soup [1]
	Broccoli [1]	Asparagus, canned [1]	Lettuce [1]	Cekur manis [1]	Mushroom, chinese, dried [1]
	Wolfberry, dried [1]	Red date [1]	Longan, dried [1]	Wolfberry, dried [1]	Red date [1]
Dinner	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]
	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]	Rice, raw, long-grain, brown [1]
	Sambal udang [1]	African bream, in coconut milk (Ikan tilapia masak lemak) [1]	Anchovy, dried, fried in chilli [1]	Black pomfret, fried (Ikan bawal hitam goreng) [1]	Red snapper cooked in tamarind [1]
	Spinach (bayam putih) [1]	Spinach, red (bayam merah) [1]	Sweet potato shoots [1]	Spinach (bayam duri) [1]	Tomato only [1]
	Kiwi [1]	Nangka [1]	Cashew apple (jambus gajus) [1]	Cempedak [1]	Banana (pisang tanduk) [1]
Supper	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]	Plain water [1]
	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]	Nuts, with salt added, dry roasted, walnuts [1]
Cost (RM)	18.60	18.30	23.80	16.70	22.40

Nutrient Consumption in a 5 Day Menu

Case 1

The nutrient consumption for a 5-day menu was recorded and plotted for each nutrient to demonstrate that the planned menu fulfils the daily nutrient requirements for teenagers aged 20 to 29. Tables 5 and 6 show the

nutrient consumption for each nutrient in the Case 1 menu, using Integer Programming (IP) and Goal Programming (GP).

Table 5: Nutrient Consumption for Each Nutrient Using IP (Case 1)

Nutrients	LB	Day 1	Day 2	Day 3		Day 4	Day 5	UB
Energy (kcal)	2075	2395	2597	2325		2238	2128	2960
Protein (g)	78	103.3	101.1	85.74		78	78	148
Fats (g)	58	98.4	98.3	84.64		72.31	68.68	99
Carbohydrate (g)	259	311.1	303.3	306.4		297.9	324.1	407
Folate (μg)	400	472.5	428	415.9		400	400	1000
Vitamin B12 (μg)	4	4.1	4	4.5		4.09	4.35	-
Vitamin C (μg)	70	100.5	533.7	179.2		385.3	180.8	2000
Vitamin D (μg)	15	15	38.5	18.5		15	15	100
Calcium (mg)	1000	1000	1036	1047.5		1000	1000	2500
Iron (mg)	14	14	24.82	31.64		23.28	44.78	45

Table 6: Nutrient Consumption for Each Nutrient Using GP (Case 1)

Nutrients	LB	Day 1	Day 2	Day 3	Day 4	Day 5	UB
Energy (kcal)	2075	**2113**	**2426**	**2430**	**2690**	**2110**	2960
Protein (g)	78	81.3	91	101.9	94.6	66	148
Fats (g)	58	**72.4**	**100.5**	**96.9**	**108.4**	**71.5**	99
Carbohydrate (g)	259	**305.3**	**322.9**	**320.5**	**353**	**330.2**	407
Folate (μg)	400	357.5	152	149.7	153.7	133	1000
Vitamin B12 (μg)	4	5.2	4.5	4.6	4	3	-
Vitamin C (μg)	70	63.4	187.7	73.1	150.7	220	2000
Vitamin D (μg)	15	10.9	9.3	17.8	31.55	25.4	100
Calcium (mg)	1000	1122	790.5	812.5	1060	571.5	2500
Iron (mg)	14	40.82	15.14	17.22	20.42	13.24	45

From the table above, it is evident that the menu planned for Case 1 successfully meets the daily nutrient requirements of teenagers aged 20 to 29 using IP. In contrast, GP approach only ensures that the values for energy, fats, and carbohydrates fall within the specified lower and upper boundaries, while other nutrients fall below the lower boundary. This indicates that GP was not suitable for menu planning, as it fails to precisely meet the required nutrient boundaries. This menu could have led to insufficient intake of essential nutrients for teenagers.

Case 2

The nutrient consumption for a 5-day menu was recorded and plotted for each nutrient to prove that the planned menu fulfils the daily nutrient requirements for teenagers aged 20 to 29. Tables 7 and 8 show the nutrient consumption for each nutrient in the Case 2 menu, using both Integer and Goal Programming.

Table 7: Nutrient Consumption for Each Nutrient Using IP (Case 2)

Nutrients	LB	Day 1	Day 2	Day 3	Day 4	Day 5	UB
Energy (kcal)	1875	2065	2236	2006	2227	2077	2680
Protein (g)	70	94.2	87.47	72.4	78.85	70	134
Fats (g)	52	67.8	73.87	64.35	70.41	63.98	74
Carbohydrate (g)	234	298.3	309.3	311.4	315	369	369
Folate (μg)	400	410.5	400	400	400	400	1000
Vitamin B12 (μg)	4	4.3	4.2	4.3	4	4.06	-
Vitamin C (μg)	70	440	190	147.3	463	449.25	2000
Vitamin D (μg)	15	20.2	37.7	19.2	15	15	100
Calcium (mg)	1000	1201	1071	1000	1000	1000	2500
Iron (mg)	29	36.82	29	29	42.39	29.79	45

Table 8: Nutrient Consumption for Each Nutrient Using GP (Case 2)

Nutrients	LB	Day 1	Day 2	Day 3	Day 4	Day 5	UB
Energy (kcal)	1875	1745	2348	2068	2129	2093	2680
Protein (g)	70	76.9	91.2	85.2	103.5	67.8	134
Fats (g)	52	67.8	85.4	82.8	72.4	46.9	74
Carbohydrate (g)	234	**241.3**	**317.5**	**286.8**	**297.4**	**298.8**	369
Folate (μg)	400	221.5	510	158.5	531.5	143.7	1000
Vitamin B12 (μg)	4	3.7	5.5	4.6	14.5	3	-
Vitamin C (μg)	70	**421.5**	**198.4**	**409.9**	**145.5**	**135**	2000
Vitamin D (μg)	15	4.3	3.3	4.2	7.8	7.75	100
Calcium (mg)	1000	697	659.5	409.9	672	683.5	2500
Iron (mg)	29	9.02	35.64	23.52	10.42	9.92	45

The figure above shows that the menu planned for Case 2 successfully meets the daily nutrient requirements of teenagers aged 20 to 29 using Integer Programming. However, the Goal Programming approach only ensures that the values for carbohydrates and vitamin C stay within the set limits, while other nutrients are below the

lower boundary. This indicates that Goal Programming is not suitable for menu planning because it cannot accurately meet the nutrient requirements. As a result, this menu might not provide enough essential nutrients for teenagers.

Comparison Method of Menu Price

Tables 9 show the daily meal costs for teenagers in both cases. The optimization approach ensures meals meet nutritional requirements at the lowest cost, with prices sourced from catering services and Chinese medicine shops for herbal ingredients.

By comparing the two methods for calculating the average cost of meals over five days for both cases, the results show that the average cost generated using Integer Programming is lower than that using Goal Programming. Integer Programming proves to be more effective in identifying cost-efficient meals while meeting the nutrient requirements, proving its reliability and practicality in optimizing dietary plans. As a result, this demonstrates that Integer Programming is the suitable approach for meal planning when the objective is to minimize costs while satisfying the nutrient needs of teenagers.

Table 9: Pricing of the menu

Day	Cost (RM)			
	Integer Programming		Goal Programming	
	Case 1	Case 2	Case 1	Case 2
1	19.20	19.30	18.70	18.60
2	15.50	16.20	18.20	18.30
3	16.10	17.50	22.60	23.80
4	20.10	20.60	18.50	16.70
5	16.10	19.90	25.10	22.40
Average cost for 5 days (RM)	17.40	18.70	20.62	19.96

From the table above, it can be observed that the daily menu prices generally range from RM15.00 to RM 25.00. By comparing the average price of the menu over five days, it is clearly shown that the Integer Programming is effective in minimize the costs while meeting nutritional requirements. The economic implications of using IP for meal optimization are crucial for public health systems. By reducing food costs while fulfilling nutritional requirements, teenagers in Malaysia can save on daily food expenses, leading to better financial management. Besides, a cost-effective meal plan can help low-income population make healthier food choices, reduce healthcare costs associated with diet-related diseases, and support the country's long-term economic stability through healthier and more productive populations [16].

Limitations of Goal Programming in Menu Planning

The underperformance of Goal Programming (GP) in this study is primarily due to its difficulty in managing conflicting goals. While it can balance multiple objectives, this often leads to the compromise of important nutrient requirements [17]. Furthermore, Goal Programming relies heavily on soft constraints, making it less accurate in meeting exact nutrient requirements compared to Integer Programming. It also struggles to adapt to changes in food availability or seasonal price fluctuations. Moreover, Goal Programming's assumption of linear relationships among objectives, which oversimplifies real-world complexities and potentially reduces the practicality of the menus developed [18].

CONCLUSION

This study successfully developed an affordable and nutritionally balanced menu for teenagers aged 20 to 29, achieved its key objectives. The focus on this age group 20 to 29 is due to their prevalence of poor dietary habits that often lead to nutrient deficiencies or health issues. First, the daily nutritional requirement for teenagers were determined using the RNI 2017 and through a case study involving interviews with a dietitian and a Chinese herbalist. Second, low-cost meal plans were created for two case studies, fulfilling nutritional needs while minimizing costs through Integer Programming. Lastly, a five-day meal plan was developed using Integer Programming (IP), Goal Programming (GP), and the Delete-Reshuffle Algorithm (DRA), ensuring variety by adjusting the menu daily, replacing or removing food items, and the inclusion of Chinese herbal foods and supplements for added health benefits.

By using IP and GP, the study showed how optimization methods could help plan balanced and cost-effective meals. The comparison revealed that while the optimal solution provided the best cost and nutrition, the near optimal solution offered the flexibility and variety, making it more practical for real-world applications. This study contributes to public health by offering a framework to resolve diet-related challenges, such as malnutrition, obesity, and nutrient deficiencies, particularly relevant for teenagers [19]. It also highlights a significant gap, while medical institutions can calculate the nutrient requirements for patients, but they often lack practical tools to design menu plans.

Integrating Traditional Chinese Medicine (TCM) and Chinese herbal ingredients into food is an innovation and cross-culture approach that bring extra health benefits beyond regular diets [20]. These herbal foods usually found in Chinese households, could be introduced worldwide and included in daily menus, making a valuable contribution to global nutrition.

The study's limitations include ignoring of food allergies, which may make the diet plans unsuitable for some individuals and reduce the practicality of the study's findings. It also focuses narrowly on one age group and is constrained by the limitations of LINGO software. Future studies could adapt the optimization models for other demographics, by adjusting dietary plan based on specific health conditions, expanding food variety, incorporating healthy herbs, and exploring new algorithms to further enhance the diet plans.

By bridging traditional dietary practices with modern optimization techniques, this study makes a meaningful contribution to public health and nutritional sciences. The findings have practical applications in daily life, workplaces, and hospitals, potentially improving health outcomes and reducing the costs.

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