Nutritious Menu Planning for Thyroid Patients by Using Integer Programming and Goal Programming

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ABSTRACT

Thyroid dysfunction is very common in Malaysia, with as many as 68% of the population diagnosed with the issue. Nonetheless, there is insufficient research on menu plans specifically created for those with thyroid disorders. This research comprises two case studies focused on developing tailored menu plans for thyroid patients through mathematical optimization techniques. The optimization methods used include Integer Programming (IP), Goal Programming (GP), and additional analysis with Delete-Reshuffle Algorithm to increase the variety of foods. The software that used in this research are LPSolve IDE and LINGO. The objective of this research is to determine the daily nutrition requirement for thyroid patients. Besides, this research aimed to apply the mathematical modelling of Integer Programming and Goal Programming to solve the diet problem of 2 case studies of thyroid patients. Furthermore, this research also proposed the menu that meet the nutritional requirement for thyroid patients with the minimum cost. The final optimal result was achieved using IP which successfully met all the nutrient and food group constraints, delivered the average cost of menu at RM15.97 for Case 1 and RM17.81 for Case 2 which is lower than GP, that resulted higher cost (RM 28.51 for Case 1 and RM 27.42 for Case 2) and failed to satisfy the nutrient constraints. This research presents practical and optimal dietary plans to assist individuals with thyroid dysfunction, addressing both nutritional sufficiency and cost-effectiveness.

Keywords: Optimization, Menu Planning, Integer Programming, Goal Programming, Thyroid Disease

INTRODUCTION

Thyroid, often called "the butterfly inside me", is a butterfly-shaped gland in the neck that regulates hormones controlling blood pressure, body temperature, heart rate, and metabolism [1]. Thyroid disease occurs when this gland malfunctions, causing physical and psychological symptoms such as anxiety, difficulty concentrating, fatigue, hair loss, and significant weight changes [2]. Nutritional deficiencies, including low levels of vital nutrients such as iodine, iron, zinc, and selenium can exacerbate thyroid diseases.

Recent studies have predicted that 200 million individuals worldwide are diagnosed with thyroid illness, making it a major global health concern [3]. Based on the Malaysian Endocrine and Metabolic Society (MEMS), thyroid dysfunction is prevalent in Malaysia, with recent research showing 3.4% hyperthyroidism, 2.1% hypothyroidism, 9.3% goitre, and 3.6% thyroid nodules. Up to 68% of the population has recently been diagnosed, with women affected than men. Goitre is more common in those under 45 and the Indian population [4].

Fig. 1 Thyroid Gland

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Optimizing diet is an important area of research when trying to prevent malnutrition and meet nutritional needs due to the lack of information and money for adequate nutrition. There are several optimization algorithms that have been applied to solve many optimization problems, such as Linear Programming, Goal Programming, Integer Programming, Fuzzy Programming, and more [5]. A dietary problem involves creating a mathematical model, applying an optimization method to solve the problem, and formulating strategies, solutions, and interpretations of results [6]. This research was done by involving these steps. Using optimization methods can helps to create personalized and effective diets that maximize nutrition and address challenges associated with thyroid conditions, at the same time propose affordable menus. Therefore, this research applies methodical and deliberate approach to meal planning for thyroid patients, to address nutritional deficiencies, reduce symptoms and improve overall health.

Thus, this research is aimed to determine the daily nutrition requirement for thyroid patients referring the range of nutrients which are lower bound and upper bound that should be intake by thyroid patients. The Recommended Nutrient Intakes for Malaysia (RNI 2017) could be the guideline and reference of lower and upper bounds in this research. Besides, this research also aimed to apply the mathematical modelling of Integer Programming and Goal Programming to solve the diet problem of 2 case studies of thyroid patients. Furthermore, this research also proposed the menu that meet the nutritional requirement for thyroid patients with the minimum cost.

MATERIALS AND METHODS

Data Collection

Most of the nutrient's information about thyroid patients was obtained from research [7], [8] and Recommended Nutrient Intake (RNI) 2017 [9]. These studies highlight various issues related to thyroid patients' nutritional intake, offering valuable insights for this research to identify the nutrients that require greater attention. Other than that, a dietitian specializing in thyroid patients' diet, provided consultation on the nutritional needs of thyroid patients and recommended suitable food items as well as eliminated food items that are not suitable for their consumption. All the food items are ensured to be suitable for serving thyroid patients. The food contained tapioca flour (bingka ubi kayu, kerepek ubi kayu, bingka ubi kayu gula merah, and kuih talam ubi kayu), and shellfish (cockles, prawn and crab) are removed for Case 1 and further elimination of high sodium foods such as curry mee, fried rice, canned beef, and others was also done for Case 2 to address the patient's high blood pressure condition.

This research consisted of 351 food items, all of which were Malaysian-style foods. This nutritional information of food was provided by the official website of the Malaysia Food Composition Database (MyFCD) [10]. These food items have been inspected and validated by the dietitian. Besides, there was also the consideration of food prices in the model. The food prices were obtained from the official website of Food Prices in Malaysia [11] and from the local grocery markets. In this research, 11 nutrients that are essential for thyroid patients are involved. There are 8 types of food groups involved in the menu of thyroid patients, and these foods form 16 dishes in six meals per day. The food groups consist of beverages, cereal flour-based, cereal meal-based, meat, vegetables, fruits, seafood, and miscellaneous. Each group of food will have a different range of daily intake.

Mathematical Modelling

To design the menu for thyroid patients, mathematical models must be developed based on nutrient consumption, cost constraints, and food group requirements. Decision variable, objective function, and constraints are the parameters of the mathematical model in the optimization problem. In this research, Integer Programming (IP) and Goal Programming (GP) will be utilized to create a nutritious menu tailored to thyroid patients. The software that is used in this research is LPSolve IDE for IP and LINGO for GP, which this two software that are free to access and student-friendly. LPSolve IDE is free and open source, making it accessible for researchers, students, and organizations with limited budgets [12]. Besides, LINGO offers a powerful modeling language that simplifies the representation of optimization problems with minimal effort [13].

Integer Programming

The objective function in IP is to minimize the cost and, at the same time, meet the nutritional requirements that are essential for thyroid patients

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

where

x_{ijk}	= Decision variable of food items, ii, 6 meals, jj, and 8 food groups, kk
c_i	= Cost for each food item
N	= Number of food items
P	= Number of meals per day
Q	= Number of food groups

The equation for the nutrient planning model included the general nutritional requirements for thyroid patients. The constraints for the general nutritional requirements:

$LB_i \leq \sum_{i=1}^{351}\sum_{j=1}^{6}\sum_{k=1}^{8} w_i x_{ijk} \leq UB_i$	(2)

where

LB	= Lower boundary of the nutrients
UB	= Upper boundary of the nutrients
w_i	= Weight of nutrient for the food

The equation for the nutrient planning model included the general food group requirements for thyroid patients. The constraints for the general food group requirements:

$\sum_{i=1}^{8} Type\ of\ food\ group(x_i) = n$	(3)

where

x_i	= Decision variables of food items
n	= No. of dishes

Goal Programming

The objective function of the GP model is a distance function that minimizes the undesired positive and negative deviations.

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Minimize Z=$\sum_{i=1}^{N}(d_i^+ + d_i^-)$ $\sum_{i=1}^{N}(d_i^+ + d_i^-)$	(4)

where

N	= Number of food items, i ii
d_i^+, d_i^-	= Positive and negative deviational variables from the goal, $g_i g_i$

The equation for the nutrient planning model included the cost requirement for the menus. The constraints for the cost requirements:

$\sum_{i=1}^{N} a_i x_i + d_i^+ + d_i^- = g_i$ $\sum_{i=1}^{N} a_i x_i + d_i^+ + d_i^- = g_i$, $i = 1,2,\dots,N$ $i = 1,2,\dots,N$	(5)
$x_i, d_i^+, d_i^- x_i, d_i^+, d_i^- \geq 0$	(6)

where

N	= Number of food items, i ii
a_i	= Cost of food items, $x_i x_i$
g_i	= Goal to be achieved for cost

The equation for the nutrient planning model included the general nutritional requirements for thyroid patients. The constraints for the general nutritional requirements:

$\sum_{l=1}^{M} a_{il} x_{il} + d_l^+ + d_l^- = LB_l$ $\sum_{l=1}^{M} a_{il} x_{il} + d_l^+ + d_l^- = LB_l$, $l = 1,2,\dots,M$ $l = 1,2,\dots,M$	(7)
$\sum_{l=1}^{M} a_{il} x_{il} + d_l^+ + d_l^- = UB_l$ $\sum_{l=1}^{M} a_{il} x_{il} + d_l^+ + d_l^- = UB_l$, $l = 1,2,\dots,M$ $l = 1,2,\dots,M$	(8)
$x_{il}, d_l^+, d_l^- x_{il}, d_l^+, d_l^- \geq 0$	(9)

where

N	= Number of food items, i ii
x_{il}	= Decision-making variable for nutrients
a_{il}	= Nutrient of food items, $x_{il} x_{il}$
LB_l	= Lower Bound of nutrients
UB_l	= Upper Bound of nutrients
d_l^+, d_l^-	= Positive and negative deviational variables from the goal, $LB_l LB_l$ and $UB_l UB_l$

The equation for the nutrient planning model included the general food group requirements for thyroid patients. The constraints for the general food group requirements:

$\sum_{k=1}^{Q} x_{ik} + d_k^+ + d_k^- = g_k$ $\sum_{k=1}^{Q} x_{ik} + d_k^+ + d_k^- = g_k$,	(10)

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$k = 1,2,\dots,Q k = 1,2,\dots,Q$	
$x_{ik}, d_k^+, d_k^- x_{ik}, d_k^+, d_k^- \geq 0 \; l = 1,2,\dots,M$	(11)

where

Q	= Number of food groups, kk
x_{ik}	= Decision-making variable for food groups
a_{il}	= Nutrient of food items, $x_{il} x_{il}$
d_k^+, d_k^-	= Positive deviational variable from goal, $g_k g_k$
g_k	= Goal to be achieved for food groups

In this research, the decision variable involved in the model of menu planning is the different types of Malaysian-style food. The combination of different dishes will be displayed in the menu lists according to the six categories of meals. The decision variable can be written as follows:

$$X_i = \begin{cases} 1 \text{ or } 2, & \text{if menu } i \text{ appear in the menu list} \\ 0, & \text{otherwise} \end{cases}$$

$i = i =$ any type of menu (12)

RESULTS AND DISCUSSION

The menu that more than one day will be developed by using LPSolve IDE for IP and LINGO for GP. A five-day menu for both Case 1 and Case 2 was generated, as outlined in the objectives. The data involved are all the 351 datasets for Case 1 and the 335 datasets for Case 2. The program will run once and try to produce more than one day's menu based on the constraints, which are the requirements of essential nutrients and food groups.

Delete-Reshuffle Algorithm

The Delete-Reshuffle Algorithm is used to minimize repetition of food and beverages, providing patients with a greater variety of choices. This method includes deleting the food that appeared in the previous day, then rerunning the result [14]. Each day's menu will feature different foods, except for plain water, brown rice, and red apples, which are to be consumed daily. There are a total of 16 dishes consumed per day in 6 meals, which are breakfast, morning tea, lunch, evening tea, dinner, and supper.

Case 1

The result of diet menus with optimized cost that use the IP approach for Day 1 until Day 5 are shown in Table 1, while the result of diet menus that use the GP approach for Day 1 until Day 5 are shown in Table 2. Not all the food items are repeated on consecutive days, and they are easily found in supermarkets or grocery stores.

Table 1: 5-day Menu of Big Data Set Using IP (Case 1)

Day	1	2	3	4	5
Breakfast	Coffee powder, instant [1] Biscuit, coconut [1] Banana	Coffee mixture, Powder [1] Oats, processed,	Coconut water [1] Bread, wholemeal [1]	Milk based diet supplement, powder [1] Cookies, peanut	Milk, cow, fresh [1] Cookies cornflakes [1]

	(pisang abu) [1]	tinned [1] Orange only [1]	Grape [1]	[1] Banana (pisang tanduk) [1]	Apple, red [1]
Morning Tea	Tea [1]	Milk, UHT, chocolate flavoured [1]	Coffee & Sugar [1]	Syrup rose (Sirap ros) [1]	Milk, UHT, full cream, recombined [1]
Lunch	Plain water [1] Rice, cooked [1] Tomato juice, canned [1] Apple, red [1] Prepared cuttlefish snack (brand k) [1]	Coffee mixture, Powder [1] Brown rice [1] Tomato only [1] Apple, red [1] Satay only [1]	Coconut water [1] Brown rice [1] Mushroom, chinese, dried [1] Apple, red [1] Prepared cuttlefish snack (brand LB) [1]	Plain water [1] Rice, coconut milk [1] Spring Onion (Daun Bawang) [1] Apple, red [1] Chicken satay [1]	Plain water [1] Rice, briyani (rice only) [1] Bean, string [1] Guava [1] Duck egg, whole [1]
Evening Tea	Orange flavoured drink, powder [1] Jelly from rokam fruit [1]	Plain water [1] Jelly crystals, strawberry flavoured [1]	Plain water [1] Sandwich with tuna fish [1]	Yogurt, strawberry [1] Milk chocolate with peanuts [1]	Soya bean milk, packet [1] Chicken wing [1]
Dinner	Plain water [1] Brown rice [1] Soya bean sprout [1] Quail egg, whole [1]	Plain water [1] Rice, chicken [1] Lettuce [1] Fish crackers, fried [1]	Plain water [1] Rice porridge, fish, instant [1] Cekur manis [1] Hen egg, whole [1]	Plain water [1] Brown rice [1] Spring Onion (Daun Bawang) [1] Fish, unspecified, dried, salt [1]	Plain water [1] Brown rice [1] Yam stalks [1] Spanish mackerel, fried (Ikan tenggiri goreng) [1]
Supper	Milk, UHT, low-fat, recombined [1]	Milk, UHT, chocolate flavored [1]	Milk powder, skim [1]	Milo [1]	Milk, UHT, full cream, recombined [1]
Cost (RM)	**11.86**	**13.85**	**16.50**	**16.77**	**20.87**

Table 2: 5-day Menu of Big Data Set Using GP (Case 1)

Day	1	2	3	4	5
Breakfast	M20ilk, UHT, full cream, recombined [1] Bread, wholemeal [1] Banana (pisang tanduk) [1]	Milo [1] Roti telur [1] Apple, red [1]	Milk, sterilised [1] Roti canai + yellow dhal gravy [1] Strawberry only [1]	Milk-based diet supplement, powder [1] Rawa dosai [1] Apple, red [1]	Yogurt Strawberry [1] Oats, processed, tinned [1] Apple, red [1]
Morning Tea	Coffee mixture, powder [1]	Tea [1]	Orange Juice [1]	Mango Juice [1]	Pineapple Juice [1]
Lunch	Plain water [1]	Plain water [1]	Plain water [1] Rice, coconut	Plain water [1]	Plain water [1]

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	Rice, cooked [1] Tomato juice, canned [1] Apple, red [1] Hen egg, whole [1]	Brown rice [1] Spinach, red (bayam merah) [1] Water Apple [1] Tuna, cooked in coconut milk [1]	milk [1] Spring Onion (Daun Bawang) [1] Apple, red [1] Satay only [1]	Rice, chicken [1] Bamboo shoot, braised, canned [1] Salak [1] Threadfin bream, fried in chilli [1]	Brown rice [1] Bean, four-angled [1] Rambutan [1] Stingray, cooked in tamarind (ikan pari masak pedas) [1]
Evening Tea	Orange flavoured drink, powder [1] Bun only [1]	Milk, UHT, chocolate flavoured [1] Vadai kacang dhal kuning [1]	Syrup rose (Sirap ros) [1] Spring roll, fried [1]	Malted milk powder [1] Spring roll [1]	Lime water [1] Spaghetti with vegetables [1]
Dinner	Plain water [1] Brown rice [1] Soya bean sprout [1] Fish satay snack [1]	Plain water [1] Rice, chicken [1] Spinach (bayam putih) [1] Sausage, Chinese [1]	Plain water [1] Brown rice Asam gelugor, pucuk [1] Threadfin bream, in soya sauce (Ikan kerisi masak kicap) [1]	Plain water [1] Brown rice [1] Asparagus, canned [1] Rendang hati chicken [1]	Plain water [1] Rice, briyani (rice only) [1] Bamboo shoot, pickled [1] Quail egg, whole [1]
Supper	Soya bean milk, unsweetened [1]	Milk, UHT, low-fat, recombined [1]	Milk powder, skim [1]	Malted milk drink, packet [1]	Apple Juice [1]
Cost (RM)	**34.25**	**23.05**	**22.77**	**30.10**	**32.40**

Case 2

Table 3 displays the diet menu results produced by the IP approach for Days 1 through 5, as well as the results obtained by the GP strategy for the same period, shown in Table 4. There were limited options available because foods high in sodium were not included in the selection process. This limitation in the variety of food items led to some repetition in the menu for Day 5, which includes tea, white bread, and coconut milk rice when using the IP approach. The menu is planned without any repetition of food items when using GP.

Table 3: 5-day Menu of Big Data Set Using IP (Case 2)

Day	1	2	3	4	5
Breakfast	Milk, UHT, full cream, recombined [1] Bread, wholemeal [1] Banana (pisang	Coffee powder, instant [1] Cookies oats [1] Apple, red [1]	Milk powder, skim [1] Cookies, peanut [1] Guava [1]	Tea [1] Bread, white [1] Apple, red [1]	Milk, sterilised [1] Bread, white [1] Pear yellow [1]

	tanduk [1]				
Morning Tea	Coffee mixture, powder [1]	Milk, cow, fresh [1]	Milk, UHT, chocolate flavoured [1]	Malted milk drink, packet [1]	Tea [1]
Lunch	Plain water [1] Rice, cooked [1] Tomato juice, canned [1] Apple, red [1] Hen egg, whole [1]	Coffee powder, instant [1] Brown rice [1] Cekur manis [1] Water Apple [1] Prepared cuttlefish snack (brand k) [1]	Plain water [1] Rice porridge, fish, instant [1] Lettuce [1] Apple, red [1] Chicken satay [1]	Plain water [1] Rice, coconut milk [1] Mushroom, chinese, dried [1] Star fruit [1] Duck egg, salted, whole [1]	Plain water [1] Rice, coconut milk [1] Pegaga gajah [1] Apple, red [1] African bream, in coconut milk (Ikan tilapia masak lemak) [1]
Evening Tea	Orange flavoured drink, powder [1] Bun only [1]	Plain water [1] Red gram porridge [1]	Milk based diet supplement, powder [1] Hot dog [1]	Tea [1] Jelly from rokam fruit [1]	Tea [1] Jelly, honey dew [1]
Dinner	Plain water [1] Brown rice [1] Soya bean sprout [1] Fish satay snack [1]	Plain water [1] Rice, chicken [1] Cekur manis [1] Duck egg, whole [1]	Plain water [1] Brown rice [1] Lettuce [1] Cuttlefish, small, fried in chilli (Sotong kecil sambal) [1]	Plain water [1] Brown rice [1] Bean, string [1] Fish curry, canned [1]	Plain water [1] Brown rice [1] Yam stalks [1] Maw in coconut milk gravy [1]
Supper	Milk, UHT, full cream, recombined [1]	Milk, UHT, low-fat, recombined [1]	Milk, UHT, chocolate flavoured [1]	Lengkong (grass jelly) [1]	Milo [1]
Cost (RM)	**13.06**	**14.80**	**17.55**	**20.82**	**23.35**

Table 4: 5-day Menu of Big Data Set Using GP (Case 2)

Day	1	2	3	4	5
Breakfast	Tea & milk [1] Roti telur [1] Watermelon [1]	Milo [1] Roti canai + yellow dhal gravy [1] Apple, red [1]	Sugar cane juice [1] Rawa dosai [1] Strawberry only [1]	Milk, sterilised [1] Oats, processed, tinned [1] Apple, red [1]	Milk-based diet supplement, powder [1] Dumpling sang yoke [1] Rambutan [1]
Morning Tea	Soya bean milk, packet [1]	Milk, UHT, low-fat, recombined [1]	Tea [1]	Orange Juice [1]	Malted milk drink, packet [1]
Lunch	Plain water [1] Rice, cooked [1] Spinach (bayam	Syrup rose (Sirap ros) [1] Rice, coconut	Plain water [1] Rice, chicken [1]	Plain water [1] Rice, briyani (rice only) [1]	Plain water [1] Rice, “oily” [1] Bean, four-

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	duri) [1] Apple, red [1] Spleen rendang (rendang limpa lembu) [1]	milk [1] Spinach (bayam putih) [1] Water Apple [1] Sausage, Chinese [1]	Asam gelugor, pucuk [1] Apple, red [1] Satay only [1]	Bamboo shoot, braised, canned [1] Salak [1] Rendang hati chicken [1]	angled [1] Apple, red [1] Quail egg, whole [1]
Evening Tea	Tea & milk [1] Vadai kacang hitam [1]	Plain water [1] Vadai kacang dhal kuning [1]	Sweet corn drink [1] Spring roll, fried [1]	Milk powder, skim [1] Soya bean curd, fried [1]	Mango Juice [1] Sandwich with chicken, salad [1]
Dinner	Plain water [1] Brown rice [1] Spinach (bayam pasir) [1] Yellow-banded travelly, in tamarind [1]	Plain water [1] Brown rice [1] Spinach, red (bayam merah) [1] Tuna, cooked in coconut milk [1]	Plain water [1] Brown rice [1] Asparagus, canned [1] Threadfin bream, in soya sauce (Ikan kerisi masak kicap)[1]	Plain water [1] Brown rice [1] Bamboo shoot, pickled [1] Threadfin bream, fried in chilli [1]	Plain water [1] Brown rice [1] Bean, French [1] Stingray, cooked in tamarind (ikan pari masak pedas) [1]
Supper	Soya bean milk, unsweetened [1]	Milk, UHT, full cream, recombine [1]	Milk, UHT, chocolate flavoured [1]	Milk, cow, fresh [1]	Grape Juice [1]
Cost (RM)	**27.20**	**23.80**	**26.30**	**27.70**	**32.10**

Nutrient Consumption

The nutrient consumption of a 5-day menu developed using IP and GP was recorded. This comprehensive analysis underscores the menu's suitability in providing balanced nutrition tailored to the specific needs of thyroid patients.

Case 1

Nutrient consumption of the Case 1 patient over 5 days, according to the planned menu, is listed in Table 5 and Table 6 for IP and GP, respectively. The bolded values in the tables are the nutrient intakes that do not fall within the nutrient boundaries; some of them do not exceed the lower bound, and some exceed the upper bound.

The findings from the analysis for Case 1, as presented in Tables 5 and 6, demonstrate a significant distinction in performance between the Integer Programming (IP) and Goal Programming (GP) methods. The IP method effectively keeps all nutrient values within the defined lower and upper limits for all 5 days. This shows the dependability of the IP method in generating viable results. Conversely, the GP method fails to comply with various nutrient constraints, which are Energy, Fats, Carbohydrate, Calcium, Sodium, Vitamin B12, C, and D, with significant breaches noticed in both the upper and lower limits. These findings suggest that the GP method finds it challenging to comply with nutrient constraints, especially regarding the management of energy, fats, carbohydrates, and essential vitamins. The failure to meet the nutrient constraints in the GP model may be attributed to the use of soft constraints in its formulation. Soft constraints, unlike hard constraints, allow for some degree of flexibility or deviation from the specified requirements. This flexibility, while intended to provide the model with more adaptability, can lead to solutions that do not strictly adhere to the desired nutrient targets. This can be improved by adjusting the nutrient boundaries and considering introducing stricter soft constraints or relaxing certain non-critical constraints to achieve a better balance.

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

Nutrient	Lower Bound	Day 1	Day 2	Day 3	Day 4	Day 5	Upper Bound
Energy (kcal)	1900	2348	2305	1919	1941	1975	2730
Fats (g)	52.78	58.46	63.26	53.94	53.66	60.96	63.33
Protein (g)	71.25	77.64	87.84	73.68	75.44	71.84	95
Carbohydrate (g)	213.75	236.20	236.80	233.91	236.80	237.20	237.5
Calcium (mg)	1000	1118.06	1048.06	1000	1000	1000	2500
Iodine (µg)	150	223.3	174.42	415.06	348.90	181.30	1100
Selenium (µg)	32	77.79	81.8	120.08	123.96	127.95	400
Sodium (mg)	1500	1809.08	1751.08	1627.09	1897.08	1500	2300
Vitamin B12 (µg)	4	5.04	4.20	5.13	4.86	25.93	-
Vitamin C (mg)	70	14103	77	77.95	85.5	206.40	2000
Vitamin D (µg)	15	16.33	15.45	60.3	15.2	15.17	100

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

Nutrient	Lower Bound	Day 1	Day 2	Day 3	Day 4	Day 5	Upper Bound
Energy (kcal)	1900	2714	**1800**	2334.11	1917	2580	2730
Fats (g)	52.78	**100.46**	57.96	**92.24**	**71.66**	**122.06**	63.33
Protein (g)	71.25	94.24	72.04	93.18	94.54	88.24	95
Carbohydrate (g)	213.75	**434.70**	279.20	**285.21**	**264.60**	**397.3**	237.5
Calcium (mg)	1000	**589.06**	1493.06	**894.16**	**417.06**	1315.06	2500
Iodine (µg)	150	201.50	410.50	200.36	345	202.80	1100
Selenium (µg)	32	122.05	127.91	83.17	209.80	92.21	400
Sodium (mg)	1500	**26.08**	1843.08	**2757.69**	**3693.08**	**2340.78**	2300
Vitamin B12 (µg)	4	9.41	13.08	**3.89**	11.3	20.24	-
Vitamin C (mg)	70	189.10	101.20	135.45	110.5	**66.20**	2000
Vitamin D (µg)	15	**11.13**	27.60	**3.66**	**3.95**	**7.28**	100

Case 2

The nutrient intake of the Case 2 patient over five days, based on the planned menu, is presented in Table 9 and Table 10 for IP and GP, respectively. The bolded values in the tables are the nutrient intakes that do not fall within the nutrient boundaries; some of them do not exceed the lower bound, and some exceed the upper bound.

In Table 7, the IP approach effectively adheres to all nutrient limits over the 5 days. Overall, the IP methodology guarantees adherence to nutrient constraints while delivering feasible and balanced outcomes. Based on Table 8, showcases numerous breaches of nutrient limits under the GP methodology. Similar violations are observed for certain nutrients (Energy, Fats, Protein, Carbohydrate, Calcium, Iodine, Sodium, Vitamin B12, and D), which fail to satisfy their respective boundary on various days, this is due to the use of soft constraints in the GP models, as applying hard constraints for nutrients does not yield a feasible solution. This condition can be ameliorated by expanding the food database to include a wider variety of nutrient-rich foods, particularly those high in Vitamin D, low in sodium, and suitable for thyroid patients.

Comparison of Menu Price

Based on Table 9, the IP method surpasses the GP method in terms of cost efficiency for both scenarios. The average prices under IP (RM15.97 for Case 1 and RM17.81 for Case 2) are considerably lower when compared to those under GP (RM28.51 for Case 1 and RM27.42 for Case 2). This implies that the IP method not only more effectively meets nutrient constraints but also reduces the cost of the menu plan, rendering it a more viable and cost-effective alternative in comparison to the GP method. On average, the price of a meal in Malaysia may vary depending on where and how you decide to dine. if you dine at a budget-friendly small eatery or in a food court, anticipate spending between RM20 and RM30 for a day. In a mid-tier restaurant, expect to spend around RM30 to RM50 per person per day. Alternatively, preparing your meals can cost around RM7 to RM15 per meal [15]. Therefore, the cost results generated using IP are reasonable and affordable for Malaysians.

CONCLUSION

In conclusion, all three 3 objectives for the research are achieved. According to the first objective, to determine the daily nutrition requirement for thyroid patients. The daily nutrient requirements for thyroid patients are determined by consulting the dietitian. The essential macronutrients are energy, fats, protein and carbohydrates and calcium while micronutrients are iodine, selenium, sodium, Vitamin B12, Vitamin C and Vitamin D, each play a vital role in maintaining the patients' health [9]. The second objective was also achieved which is to apply mathematical modelling in solving the diet problem for 2 different cases of thyroid patients by using Integer Programming and Goal Programming. The results confirm that IP is a more effective method for meeting nutrient constraints and producing feasible, balanced menu plans, while GP requires further refinement to improve its adherence to nutritional limits. The average price of the menu produced by IP is RM15.97 for Case 1 and RM17.81 for Case 2. The third objective is to propose a menu that meets the nutritional requirements for thyroid patients at the minimum cost. The 5-day menu with the minimum cost and balanced diet that meets the nutrient requirement is also proposed by applying the Delete-Reshuffle to ensure the variety of food items. In future research, researchers can focus on menu planning tailored to different age groups and health conditions. Researchers could also compare dynamic programming with integer programming, as both are optimal solution methods, to identify the better approach. Additionally, future research can leverage AI to analyze large-scale dietary and health data to uncover patterns and trends. This can help refine the menu planning model and improve its applicability across diverse populations. Nevertheless, IP and GP can be extended to manage dietary constraints for various diseases by incorporating disease-specific nutritional needs and restrictions. For example, in cardiovascular diseases, IP can be used to minimize sodium and unhealthy fats while optimizing the intake of heart-healthy nutrients like omega-3 fatty acids and fiber. In conditions like cancer, GP can prioritize nutrient-dense foods, such as increasing protein intake and managing inflammation, while still balancing overall calorie intake.

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

Nutrient	Lower Bound	Day 1	Day 2	Day 3	Day 4	Day 5	Upper Bound
Energy (kcal)	1450	2002	1533	1643	2085	1545	2200
Fats (g)	40.28	42.96	40.46	46.16	46.96	42.56	48.33
Protein (g)	54.38	63.94	70.14	71.74	57.54	55.34	72.5
Carbohydrate (g)	163.13	177.40	179.50	180.10	180.80	181.20	181.25
Calcium (mg)	1000	1072.06	1003.06	1081.06	1003.06	1040.06	2500
Iodine (μg)	150	295.68	219.20	252.60	218.20	152	1100

Selenium (µg)	24	90.21	11.64	99.24	104.79	83.40	400
Sodium (mg)	1500	1921.08	1527.08	1675.08	2282.58	1579.08	2300
Vitamin B12 (µg)	4	20.80	9.69	4.73	61.20	9.48	-
Vitamin C (mg)	70	176.60	82.80	179	88.60	81.60	2000
Vitamin D (µg)	15	15.80	15.26	15.45	61.10	15.10	100

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

Nutrient	Lower Bound	Day 1	Day 2	Day 3	Day 4	Day 5	Upper Bound
Energy (kcal)	1450	1684	2063	**2204**	**2027.11**	1682	2200
Fats (g)	40.28	**52.56**	**74.36**	**67.36**	**70.34**	**54.96**	48.33
Protein (g)	54.38	62.14	**75.14**	**93.04**	**94.38**	67.04	72.5
Carbohydrate (g)	163.13	**285.10**	**303.10**	**270.82**	**288.61**	**306**	181.25
Calcium (mg)	1000	**595.06**	1516.06	**662.06**	**840.16**	**502.06**	2500
Iodine (µg)	150	213.20	389.70	**143.40**	201.96	347.90	1100
Selenium (µg)	24	131.06	96.91	105.19	191.67	107.30	400
Sodium (mg)	1500	**1018.08**	**3093.08**	**2537.08**	**3644.69**	1833.08	2300
Vitamin B12 (µg)	4	9.86	12.08	**3.65**	12.15	9.84	-
Vitamin C (mg)	70	77.10	102.10	152	72.35	133.80	2000
Vitamin D (µg)	15	**11.88**	25.80	**7.3**	**7.31**	**4.38**	100

Table 9: Comparison of Price between Case 1 and Case 2

Day	**Price (RM)**			
	Integer Programming		**Goal Programming**	
	Case 1	Case 2	Case 1	Case 2
1	11.86	13.06	34.25	27.20
2	13.85	14.80	23.05	23.80
3	16.50	17.00	22.77	26.30
4	16.77	20.82	30.10	27.70
5	20.87	23.35	32.40	32.10
Average Price (RM)	**15.97**	**17.81**	**28.51**	**27.42**

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