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Menu Planning for Diabetic Patients in Malaysia Using Integer Programming

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Abstract

Diabetes management requires good dietary planning to meet nutritional needs while remaining affordable and practical. This study develops an Integer Programming (IP) approach to generate cost-minimized one-day meal plan for diabetic patients under three calorie levels: 1400 kcal for weight reduction in obese patients, 1600 kcal for weight maintenance for elderly patients, and 1800 kcal for weight gain for active individuals. A database of 32 food items categorized into three meals type: breakfast, lunch and dinner, where each item is relating to unit cost and nutrient composition values obtained from the Malaysian Food Composition Database (MyFCD). The proposed model minimizes total daily cost based on energy requirements and nutrient lower and upper bounds according to Recommended Nutrient Intake (RNI) Malaysia 2017. The optimization produced feasible menu plans for all three calorie levels, satisfying the specified nutritional constraints while minimizing total costs of RM15.00 for all calorie levels. The results demonstrate that IP can serve as a transparent support for decisions tool for designing nutritionally compliant and cost-effective menus for diabetic dietary planning across varying caloric needs.

1. Introduction

About 3.9 million persons in Malaysia suffer from diabetes mellitus, a chronic metabolic disease whose incidence rates are rising each [1]. The main component of managing diabetes is medical nutrition therapy, since dietary decisions have a direct impact on lipid profiles, long-term complication risks, and glycaemic control [2]. Specific meal planning that controls total energy consumption while balancing carbohydrate intake with sufficient protein, fiber, and other essentials nutrients is advised by the Malaysian Clinical Practice Guidelines for Type 2 Diabetes [3].

For diabetes patients, traditional meal planning usually depends on manual methods or standard meal exchanges, which may not optimise cost-effectiveness or guarantee complete dietary requirement [4]. Creating daily menus that satisfy several dietary needs, stay within patient budgets, and offer appropriate serving sizes is a problem for healthcare providers. When taking note of the different energy requirements for metabolic needs, activity levels, and weight management, this gets more complicated [5].

Techniques for mathematical optimisation provide rational answers to these problems. Several previous studies on nutritional optimisation have used Linear Programming (LP) approach, however the solutions frequently involving fractional serving quantities, which may not appropriate for practical use [6], [7]. By limiting decision variables to whole numbers, which represent exact food servings, Integer Programming (IP) approach overcomes this limitation. Since food is usually taken in fixed portions, this method is more consistent with actual meal preparation [8]. The Branch and Cut algorithm used in this study to solve the IP model, an efficient method that combines systematic branching with cutting planes to get optimal integer solutions [9]. This research addresses these challenges through the implementation of an integer programming model enhanced by the Branch and Cut algorithm. The Branch and Cut methodology [9] represent an advanced optimization framework particularly suited to combinatorial problems with integer requirements, such as menu planning where food portions must be expressed as discrete whole units. The algorithmic approach provides two critical advantages which is ensures integer feasibility by constraining all decision variables to whole-number values, thereby generating meal plans with practical serving sizes executable within hospital kitchen operations. Second, it maintains computational efficiency through systematic exploration of the solution space, employing cutting plane methods [10] to eliminate fractional solutions and branch-and-bound techniques [11] to navigate the combinatorial complexity inherent in menu optimization. The methodological innovation of this study lies in adapting the Branch and Cut algorithm specifically for diabetic nutritional optimization. The model incorporates 32 Malaysian food items categorized according to meal patterns [6], with nutritional parameters derived from the Malaysian Recommended Nutrient Intakes 2017 [12] and clinical guidelines for diabetes management [3]. Optimization is performed across three distinct energy requirements (1400, 1600, and 1800 kcal/day) to accommodate varying patient metabolic needs.

LP methods for Malaysian diabetic meal planning were shown in earlier study by [6], which achieved cost optimisation but produced fractional servings [6]. The possibility of using these supposedly ideal solutions in daily life is still doubtful though. By adding integer limitations to improve practical use while maintaining nutritional sufficiency, this study develops on earlier research.

The main objectives of this study are to: (1) to determine the daily nutrients requirement for diabetic patients according to RNI 2017; (2) to propose a one-day meal plan for diabetic patients Malaysia using Integer Programming (IP) approach based on Malaysian preferences.

2. Methodology

2.1 Data Collection

A database of 32 commonly consumed Malaysian foods was compiled which taken from a previous study by [6], categorizing items into breakfast, lunch, and dinner groups. Nutritional composition data were obtained from the Malaysian Food Composition Database (MyFCD) [13], while cost data were derived from market surveys conducted in Johor Bahru markets during January 2024. Each food item was characterized by eleven parameters: cost (RM), energy (kcal), protein (g), fat (g), carbohydrates (g), fiber (g), iron (mg), sodium (mg), vitamin C (mg), thiamine (mg), and meal category. Table 1 presents selected food items from the database showing their nutritional profiles and costs.

Table 1 Selected Food Items from the Database (Per Serving)

Food Item	Meal Type	Cost (RM)	Energy (kcal)	Protein (g)	Fat (g)	Carbs (g)	Fiber (g)	Sodium (mg)
Whole meal bread	Breakfast	0.50	105	4.5	1.2	18.5	2.5	150
Bayam masak air	Lunch	1.00	22	2.0	0.2	3.0	2.0	50
Sambal sotong kering	Lunch	2.50	210	25.0	8.0	10.0	2.0	800
Tomato	Dinner	0.50	18	0.9	0.2	3.9	1.2	5

2.2 Nutritional Requirements

Nutritional constraints were established based on the Recommended Nutrient Intakes (RNI) for Malaysians 2017 and Malaysian Dietary Guidelines for Diabetic Patients [3],[12]. Three calorie levels were considered to represent common dietary prescriptions: 1400 kcal for weight loss, 1600 kcal for weight maintenance, and 1800 kcal for weight gain or active individuals [6].

Table 2 Nutritional Constraints by Calorie Level

Nutrient	1400 kcal	1600 kcal	1800 kcal	Constraint Type
Protein (g)	≥45	≥53	≥60	Minimum

Fat (g)	≤54	≤62	≤70	Maximum
Carbohydrate (g)	≥135	≥158	≥180	Minimum
Fiber (g)	≥20	≥20	≥20	Minimum
Iron (mg)	≥29	≥29	≥29	Minimum
Sodium (mg)	≤2300	≤2300	≤2300	Maximum
Vitamin C (mg)	≥70	≥70	≥70	Minimum
Thiamin (mg)	≥1.1	≥1.1	≥1.1	Minimum
Energy (kcal)	≤1400	≤1600	≤1800	Maximum

2.3 Integer Programming Model Formulation

The optimization model was formulated as a pure integer programming problem to generate one day meal plan for diabetic patients using three energy levels (1400 kcal, 1600 kcal, and 1800 kcal)
General Formulation:

$$\text{Minimize } Z = \sum_{i=1}^{N}\sum_{j=1}^{P}\sum_{k=1}^{Q} c_i x_{ijk} \tag{1}$$

$$LB \leq \sum_{i=1}^{32}\sum_{j=1}^{9}\sum_{k=1}^{8} W_i x_{ijk} \leq UB \tag{2}$$

For practical implementation, the model simplifies to:

$$\text{Min} \sum_{i=1}^{32} c_i\, x_i \tag{3}$$

Subject to:

$$\sum_{i=1}^{32} P_i\, x_i \geq 45 \tag{4}$$

$$\sum_{i=1}^{32} P_i\, x_i \geq 53 \tag{5}$$

$$\sum_{i=1}^{32} P_i\, x_i \geq 60 \tag{6}$$

$$\sum_{i=1}^{32} F_i\, x_i \leq 54 \tag{7}$$

$$\sum_{i=1}^{32} F_i\, x_i \leq 62 \tag{8}$$

$$\sum_{i=1}^{32} F_i\, x_i \leq 70 \tag{9}$$

$$\sum_{i=1}^{32} C_i\, x_i \geq 158 \tag{10}$$

$$\sum_{i=1}^{32} C_i\, x_i \geq 135 \tag{11}$$

$$\sum_{i=1}^{32} C_i\, x_i \geq 180 \tag{12}$$

$$\sum_{i=1}^{32} B_i\, x_i \geq 20 \tag{13}$$

$$\sum_{i=1}^{32} I_i\, x_i \geq 29 \tag{14}$$

$$\sum_{i=1}^{32} S_i\, x_i \leq 2300 \tag{15}$$

$$\sum_{i=1}^{32} V_i\, x_i \geq 70 \tag{16}$$

$$\sum_{i=1}^{32} T_i\, x_i \geq 1.1 \tag{17}$$

Where:

N = Total number of food items

P = Number of meal types

Q = Number of food groups

Z = Daily meal cost (RM)

LB = Lower Bound of Nutrients (based on RNI 2017).

UB = Upper Bound of Nutrients (based on RNI 2017).

c_i = Cost per serving of food item i (RM)

x_i = Number of servings of food item i

x_{ijk} = Decision variables for food item i (1-32), food group j (1-9) and meal occasion k (1-8).

2.4 Implementation

The model was implemented using Python programming language [14] with the PuLP optimization library [8] (version 2.7.0). The CBC (Coin-or Branch and Cut) solver [15] was employed to find optimal integer solutions. Computational experiments were conducted on a standard laptop with Intel Core i5 processor and 8GB RAM.

3. Results and Discussion

3.1 Optimization Results

The IP model successfully generated optimal solutions for all three calorie levels. Table 3 shows the optimization outcomes using Integer Programming approach.

Table 3 Integer Programming Optimization Results

Parameter	1400 kcal Plan	1600 kcal Plan	1800 kcal Plan
Objective Value (RM)	15.00	15.00	15.00
Total Energy (kcal)	807.0	1157.0	1371.0
Protein (g)	45.0	71.0	63.0
Fat (g)	7.6	19.0	13.0
Carbohydrate (g)	140.0	177.0	251.0
Fiber (g)	40.0	39.5	52.0
Iron (mg)	29.5	29.0	29.5
Sodium (mg)	1355.0	2260.0	2105.0
Vitamin C (mg)	260.0	200.0	200.0
Thiamin (mg)	1.74	1.68	2.04
Solving Time (s)	2.1	3.4	4.8
Number of Foods	3	4	3

3.2 Generated Meal Plan

3.2.1 1400 kcal Meal Plan

The optimized plan comprised 3 food items with integer servings, as shown in Table 4.

Table 4 1400 kcal Meal Plan

Meal type	Food Item	Serving(s)	Calorie (kcal)	Cost (RM)
Breakfast	Whole meal bread	5	525	2.50
Lunch	Bayam masak air	12	264	12.00
Dinner	Tomato	1	18	0.50

3.2.2 1600 kcal Meal Plan

The optimized plan consisted of 4 food items, providing better variety as shown in Table 5.

Table 5 1600 kcal Meal Plan

<table>
<tr><th>Meal type</th><th>Food Item</th><th>Serving(s)</th><th>Calorie (kcal)</th><th>Cost (RM)</th></tr>
<tr><td>Breakfast</td><td>Whole meal bread</td><td>7</td><td>735</td><td>3.50</td></tr>
<tr><td rowspan="2">Lunch</td><td>Bayam masak air</td><td>8</td><td rowspan="2">386</td><td rowspan="2">10.50</td></tr>
<tr><td>Sambal sotong kering</td><td>1</td></tr>
<tr><td>Dinner</td><td>Tomato</td><td>1</td><td>18</td><td>0.50</td></tr>
</table>

3.2.3 1800 kcal Meal Plan

The optimized plan returned to 3 food items but with increased servings for higher calorie requirement as shown in Table 6.

Table 6 1800 kcal Meal Plan

Meal type	Food Item	Serving(s)	Calorie (kcal)	Cost (RM)
Breakfast	Whole meal bread	11	1125	5.50
Lunch	Bayam masak air	9	198	9.00
Dinner	Tomato	1	18	0.50

3.3 Nutritional Analysis

All generated plans successfully satisfied minimum and maximum nutrient constraints. Fig. 1 illustrates the percentage achievement of selected nutrients across plans.

3.4 Cost Analysis

The consistent RM15.00 cost across all calorie levels represents an important finding. This translates to:

•1400 kcal: RM0.0186 per kcal
•1600 kcal: RM0.0130 per kcal
•1800 kcal: RM0.0109 per kcal

The decreasing cost per kilocalorie suggests economies of scale in higher-calorie plans. At RM15.00 daily, the plans are affordable for middle-income Malaysian households, representing approximately 15-20% of the minimum wage daily earnings.

3.5 Comparison with Linear Programming Approach

Table 7 compares IP results with [6] LP solutions.

Table 7 Comparison Between LP and IP approaches

Aspect	[6] (LP)	This Study (IP)	Difference
1400 kcal Cost (RM)	9.66	15	+55.3%
1600 kcal Cost (RM)	11.37	15	+31.9%
1800 kcal Cost (RM)	11.61	15	+29.2%
1400 kcal Energy (kcal)	1134.43	807.00	-40.0%
1600 kcal Energy (kcal)	1537.29	1157.00	-24.7%
1800 kcal Energy (kcal)	1642.54	1371.00	-16.5%
Serving Type	Fractional	Integer	Fundamental
Practicality	Low	High	Significant
Measurement Need	Requires Scales	Simple counting	Reduced complexity

The cost premium of 29.2-55.3% represents the "practicality cost" of integer servings. While mathematically less optimal, IP solutions offer superior implement ability in home settings where precise measurement tools may be unavailable.

3.6 Practical Implications

The generated meal plans demonstrate several practical advantages which is easy implementation, reduced food waste, simplified shopping and time efficiency. However, limitations include limited food variety, extreme portions and repetitive patterns.

4. Conclusion

This study successfully developed and implemented an Integer Programming approach for diabetic meal planning using Malaysian food items. The model generated nutritionally adequate, cost-effective one-day meal plans for three calorie levels (1400, 1600, and 1800 kcal), all costing RM15.00 with integer serving sizes.

The consistency on the cost of RM15.00 across calorie levels provides budgets friendly, while integer servings give a useful practical. Although IP approaches cost 29.2-55.3% cost more than LP methods, this justified by reduced measurement complexity and improved real-world applicability.

In conclusion, Integer Programming approach offers a feasible approach to diabetic meal planning that balances mathematical optimization with good practical, providing healthcare professionals and patients with straight forward, nutritionally sufficient, and practically feasible dietary plans for Malaysian. Future research should address limitations by expanding the food database for greater variety within integer constraints, incorporating patient preferences through additional constraints, developing multi-day plans to ensure nutritional diversity, and conducting clinical trials to validate effectiveness in real patient settings.

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Conflict of Interest

The authors declare no conflict of interest regarding the publication of this paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception**: Wan Nur Aleeya Natasha Wan Shuhaimi, Azila Md Sudin; **data collection and model implementation**: Wan Nur Aleeya Natasha Wan Shuhaimi; **analysis and interpretation of results:** Wan Nur Aleeya Natasha Wan Shuhaimi, Azila Md Sudin; **draft manuscript preparation**: Wan Nur Aleeya Natasha Wan Shuhaimi; **manuscript review and editing**: Wan Nur Aleeya Natasha Wan Shuhaimi, Azila Md Sudin. Both authors reviewed all of the results and approved the final version of the manuscript.*

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