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Research on the Optimization of Nutritious Meal Preparation in Campus Canteens Based on Mathematical Programming

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Abstract

This paper addresses the challenge of balancing nutritional equilibrium and cost control in nutritious meals provided by campus cafeterias, and constructs a research framework based on optimization methods. First, a linear programming model is established, with minimizing costs as the objective function. Drawing on nutritional data from The Chinese Food Composition Table (6th Edition) and ingredient price data from multiple regional markets in July 2025, constraint conditions are set for core nutrients such as staple foods, protein, calcium, iron, and vitamin C, and the model is solved using programming methods. The results show that the model can significantly reduce ingredient costs while meeting the daily nutritional needs of middle school students. However, they also indicate that the optimal solution involves a relatively limited range of ingredients, lacking meat and egg products, which is unfavorable for dietary diversity and practical acceptability. To overcome this limitation, this paper further proposes introducing a nonlinear programming model into the research, adding constraints on ingredient grouping and diversity, thereby constructing a more balanced and feasible optimization scheme for campus nutritious meals. This study provides new modeling ideas and theoretical references for the scientific meal preparation in campus cafeterias and the formulation of relevant policies.

Keywords: Campus Cafeteria Nutritious Meals, Linear Programming, Nonlinear Programming, Optimal Ingredient Combination, Optimization Model.

Background of the Problem

Globally, school meals are widely recognized as an important public policy tool for improving children's nutrition, enhancing academic performance, and promoting healthy development. Many countries and organizations have issued mandatory nutritional standards to regulate school menus. Taking the United States as an example, under the impetus of the Healthy, Hunger-Free Kids Act (2010), its National School Lunch Program (NSLP) clearly specifies upper limits for school meals in terms of energy, sodium, saturated fat, etc [1]., and requires the provision of a variety of fruits, vegetables, and whole grains. Since 2014, the United Kingdom has implemented the School Food Standards, which regulate the frequency of supply for different food categories and prohibit sugary drinks and highly fried foods on school campuses. The World Health Organization (WHO) recommends that children's daily intake of added sugar should be less than 10% of total energy and sodium intake less than 2 grams; these indicators have been incorporated into school meal standards by many countries. China's school meal standards take "food safety as the bottom line and nutritional balance as the goal[2]". In accordance with the Dietary Guidelines for Chinese Residents (2022), school lunches should provide 30% to 40% of the daily energy intake, and meet the basic nutritional requirements of 140-160 grams of staple foods, 26.25-30 grams of protein, no less than 65 mg of vitamin C, no less than 12 mg of iron, and no less than 400 mg of calcium [3].

In recent years, China has vigorously promoted the development of nutritious campus meals, requiring schools to strictly control links such as meal preparation, procurement, and processing to ensure students' food safety and nutritional balance. However, in the actual implementation process, schools are faced with the dual pressure of "nutritional needs" and "cost control", and problems such as poor meal quality, substandard nutrition, monotonous menus, and tight funds have emerged in some regions.

From the perspectives of nutritional science and operational optimization, this paper attempts to construct linear and nonlinear programming models. Combining data from the Chinese Food Composition Table and ingredient prices across multiple regions, the paper comprehensively considers nutritional intake standards and ingredient costs to formulate an optimized campus nutritious meal plan that is both healthy and economical.

Model Preparation

Nutrient Classification

In practical research, nutrients are classified in great detail, covering multiple dimensions such as energy, protein, fat, dietary fiber, vitamins, and minerals. However, if all nutrients were directly incorporated into the optimization model one by one, it would not only significantly increase the model's complexity but also create difficulties in data acquisition and constraint setting. To ensure the scientific rigor of the research while improving the model's operability, this paper simplifies and categorizes ingredients into three major groups—staple foods, protein-rich foods, and vegetables—based on the core nutritional requirements outlined in the Dietary Guidelines for Chinese Residents (2022) and the Dietary Reference Intakes (DRIs) for Chinese Residents. This classification method covers the main energy source (staple foods), high-quality protein supply (legumes, meat, poultry, fish, eggs, dairy products, etc.), and primary source of vitamins and minerals (vegetables) in students' daily diets. It not only aligns with the basic principle of nutritional balance but also facilitates further research.

To maintain scientific rigor while enhancing the model's simplicity, this paper, with reference to the Dietary Guidelines for Chinese Residents (2022) and the Dietary Reference Intakes (DRIs) for Chinese Residents, and by drawing on international experience such as the U.S. National School Lunch Program (NSLP) and the UK School Food Standards, classifies ingredients into three major categories: staple foods, protein-rich foods, and vegetables. This classification not only conforms to the principle of nutritional balance emphasized in both domestic and international nutritional documents but also provides convenience for the construction of the subsequent optimization model.

Data Sources

For the specific selection of ingredients, this paper identifies grains such as rice, flour, and corn as staple foods; high-quality protein sources including tofu, eggs, chicken breast, lean pork, dried tofu sheets, chicken liver, and tilapia; and vegetables like green peppers, broccoli, and spinach. These ingredients were chosen primarily based on the following three considerations:

Comprehensive Nutrition: Grains provide energy and partial protein; animal and plant-based protein ingredients can supplement essential amino acids, iron, calcium, and vitamin A; vegetables are rich in vitamin C, dietary fiber, and minerals. The combination of these three categories can fully meet the daily core nutritional needs of middle school students.

Cost And Market Adaptability: These ingredients cover a clear price range, including both common low-cost ingredients and some higher-priced ones with outstanding nutritional value. This makes them suitable for exploring the balance between nutrition and cost. Meanwhile, these ingredients are in sufficient supply in the summer market and can be prepared in diverse cooking ways, which helps avoid the problem of monotonous menus.

Availability And Universality: The selected ingredients are common varieties in markets across different regions, featuring strong operability and universal applicability. This ensures that the research conclusions can be promoted to the practice of campus cafeterias in various areas.

Based on the above-selected ingredients, the data in Tables 1 to 5 were obtained through data retrieval, as follows:

Table 1: Daily Dietary Nutrient Requirements for Students

Staple Foods (g)	Protein (g)	Calcium (mg)	Iron (mg)	Vitamin C (mg)
140-160	26.25-30	no less than 400	no less than 12	no less than 65

Table 2: Content of Main Nutrients in Selected Staple Foods (Content per 100g)

Ingredients	Protein	Calcium	Iron	Vitamin C
Rice	7.4g	13mg	2.3mg	0mg
standard flour	11.2g	31mg	3.5mg	0mg
Corn	4.0g	14mg	1.1mg	16mg

Table 3: Main Nutrient Contents of Protein-Preferred Ingredients (Per 100g)

Ingredients	Protein	Calcium	Iron	Vitamin C
Tofu	12.2g	138mg	2.5mg	0mg
egg	13.3g	56mg	2.0mg	0mg
Chicken breast	20.8g	9mg	0.6mg	0mg
Lean pork	20.3g	6mg	3.0mg	0mg
Dried tofu sheets	24.5g	239mg	3.6mg	0mg

Chicken liver	18.2g	21mg	8.2mg	7mg
Tilapia	18.4g	12mg	0.9mg	0mg

Table 4: Main Nutrient Contents of Selected Vegetables (Per 100g)

Ingredients	Protein	Calcium	Iron	Vitamin C
Green pepper	1.0g	15mg	0.7mg	62mg
Broccoli	4.1g	67mg	1.0mg	51mg
Spinach	2.6g	66mg	2.9mg	32mg

Table 5: Price List of Selected Ingredients (RMB/kg)

	Ingredients	Price
Staple Foods	Rice	4.2
	standard flour	3.8
	Corn	1.72
Protein	Tofu	5
	egg	10.5
	Chicken breast	19.8
	Lean pork	24
	Dried tofu sheets	27.8
	Chicken liver	10.75
	Tilapia	20
Vegetables	Green pepper	8
	Broccoli	9.5
	Spinach	7

The nutritional data used in this study is sourced from the Chinese Food Composition Table (6th Revised Edition, Standard Version). To ensure representativeness and practicality, the price data is collected from multiple channels, including: Meituan Youxuan (wholesale prices in Beijing, July 2025), Zhinongtong (wholesale prices in Hangzhou, July 2025), Beijing Xinfadi Agricultural Products Wholesale Market (quotations in July 2025), JD Fresh (bulk purchase prices, July 2025), and Huinong.com (data in July 2025).

Optimization Models

Regarding research methods for campus nutritious meals, existing scholars mostly adopt questionnaires and interviews to collect data on students' eating habits, satisfaction, and acceptance, or use randomized controlled trials to compare differences in nutrient intake and health levels between intervention groups and control groups. These methods can well reflect the implementation effect of nutritious meals, but they are mainly limited to the result evaluation level and lack quantitative analysis on how canteens should select ingredients under the constraints of nutritional needs and funding. Based on this, this study selects linear programming models and nonlinear programming models to conduct research on campus canteen nutritious meals. The Linear Programming (LP) model has a core idea of maximizing or minimizing a linear objective function under the premise of satisfying a set of linear constraints [4-5]. In linear programming, decision variables, the objective function, and constraints must all be linear [6]. When applied to the research on campus nutritious meals in this paper, the objective function is to minimize ingredient costs, and the constraint is that nutrient intake must meet the recommended intake. This makes it possible to obtain the menu combination with the lowest cost. However, the final selection of such research will only include the cheapest vegetables and soy products; therefore, further optimization can be achieved by selecting a nonlinear programming model. The Nonlinear Programming (NLP) model refers to an optimization model where there is a nonlinear relationship in the objective function or constraints [7]. Compared with linear programming, it is more suitable for describing complex real-world problems. In the research on campus nutritious meals, nonlinear programming can be used to introduce "ingredient diversity" and add nonlinear constraints such as increasing the number of ingredient types. For example, under the premise of a given budget, the number of ingredient types should be greater than a certain value. The nonlinear programming model can better meet actual meal supply needs. The optimization models in this paper take ingredient consumption as the decision variable, with cost minimization as the objective function, and incorporate requirements such as meeting nutrient standards, ingredient grouping, and budget limitations into the constraints. The linear programming model can yield the solution with the lowest cost; in the nonlinear programming model, ingredient diversity constraints are further added to make the results more in line with actual meal supply needs. These two types of models reflect different levels of "theoretical optimality" and "practical feasibility" respectively.

Model Establishment and Solution

Cost-Minimization Model

Model Establishment

1. Definition of Decision Variables.
Assume there are a total of n types of ingredients selected in the study. Letx_irepresent the quantity (unit: grams) of the "$i=1,2,\ldots,n$" ingredient, where $x_i \geq 0$.
2. Definition of Objective Function
Suppose the unit price of the i ingredient is p_i(unit: RMB/gram). The total cost is then $Z=\sum_{i=1}^{n} p_i x_i$. With the goal of minimizing the cost, the objective function is: $\min Z=\sum_{i=1}^{n} p_i x_i$
3. Definition of Constraints
Let a_{ij} denote the content (unit: mg or g) of the j th nutrient in the i th ingredient, and b_{ij} represent the recommended daily intake of the j th nutrient for students. The daily intake of this nutrient by students must satisfy: $\sum_{i=1}^{n} a_{ij} x_i \geq b_{ij}$. Additionally, the quantity of each ingredient cannot be negative, $x_i \geq 0$
In summary, the linear programming model can be expressed as:

$$\min Z=\sum_{i=1}^{n} p_i x_i$$

$$\text{S.t.}\begin{cases}\sum_{i=1}^{n} a_{ij} x_i \geq b_{ij} \\ x_i \geq 0\end{cases}$$

The linear programming model in this paper takes the quantity of each type of ingredient $x_1, x_2, \ldots, x_{13}$ as the decision variable, sets minimizing the total cost as the objective function, and is established under the constraints of meeting nutrient standards and non-negative ingredient quantities.

Model Solution

Based on the model established in Section 3.1.1, this paper takes the 13 selected ingredients as decision variables, where: $x_1, x_2, \ldots, x_{13}$
respectively represent the quantities of rice, standard flour, corn, tofu, egg, chicken breast, lean pork, dried tofu sheets, chicken liver, tilapia, green pepper, broccoli, and spinach. By substituting the specific values of each parameter, the model's specific form is obtained.

Objective Function:

$$\text{MinZ} = 10^{-4}\ (42x_1 + 38x_2 + 17.2x_3 + 50x_4 + 105x_5 + 198x_6 + 240x_7 + 278x_8 + 105x_9 + 200x_{10} + 80x_{11} + 95x_{12} + 70x_{13})$$

Constraints:

staple food: $140 \leq x_1 + x_2 + x_3 \leq 160$
Vitamin C:

$$10^{-2}(16x_3 + 7x_9 + 62x_{11} + 51x_{12} + 32x_{13}) \geq 65$$

Protein:

$$26.25 \leq 10^{-3}(74x_1 + 112x_2 + 40x_3 + 122x_4 + 133x_5 + 208x_6 + 203x_7 + 245x_8 + 182x_9 + 184x_{10} + 10x_{11} + 41x_{12} + 26x_{13}) \leq 30$$

Iron:

$$10^{-3}(23x_1 + 35x_2 + 11x_3 + 25x_4 + 20x_5 + 6x_6 + 30x_7 + 36x_8 + 70x_9 + 9x_{10} + 7x_{11} + 10x_{12} + 29x_{13}) \geq 12$$

Calcium:

$$10^{-2}(13x_1 + 31x_2 + 14x_3 + 138x_4 + 56x_5 + 9x_6 + 6x_7 + 239x_8 + 21x_9 + 12x_{10} + 15x_{11} + 67x_{12} + 66x_{13}) \geq 400$$

The model was solved using the "Solver" function in Excel, yielding the results
x_3=140.00, x_4=139.19, x_{13}=285.32 The quantities of the remaining ingredients equal 0 gram. Substituting these values into the linear programming model for calculation yields a minimum cost of 2.93 RMB.

Analysis of Model Results

After solving the linear programming model, the aforementioned ingredient combination with the lowest cost (under the premise of meeting nutrient standards) can be obtained. However, this result also reveals obvious shortcomings:

Excessively Single Ingredients: Since linear programming tends to select ingredients with the highest cost - effectiveness, the optimal solution focuses on a small number of low - cost vegetables or soy products with high nutrient density. This leads to a monotonous menu structure and a lack of diversity.

Poor Practical Acceptance: Although the nutrient intake requirements are theoretically met, if students rely on a small number of fixed ingredients for their daily meals over the long term, they will easily experience taste fatigue. This makes it difficult to truly improve their meal satisfaction.

Based on the above shortcomings, the model is improved by adding constraints on ingredient diversity. This helps to find a balanced solution that better meets the actual meal supply needs between cost and nutritional balance.

Ingredient Diversity Model

Model Establishment

The linear programming model can obtain the minimum-cost solution under the premise of meeting nutrient standards. However, since both its objective function and constraints are linear, the solution often concentrates on a small number of ingredients with the highest cost-effectiveness, resulting in a lack of diversity in the menu. To address this shortcoming, this study further introduces a nonlinear utility function based on integer programming, and constructs a (Mixed-Integer Nonlinear Programming (MINLP) model), making the results more in line with the actual needs of campus meal supply [8].

Definition of Decision Variables

$x_i \geq 0$, the quantity of the i th ingredient (unit: gram);

$y_i \in \{0,1\}$ Whether to select ingredient i: if selected, y_i=1; otherwise, y_i=0.

(2) Definition of the Objective Function.

$$\max U(x,y)=\sum_{i=1}^{n} \sqrt{x_i}\, y_i$$

Among them, $\sqrt{x_i}$ is a diminishing marginal utility function, which reflects that the more of the same ingredient is consumed, the smaller its marginal utility becomes. In other words, the more one eats of the same ingredient, the smaller the contribution to diversity from each additional amount consumed. The multiplication with y_iensures that only selected ingredients generate utility. This design enables the model to automatically tend to select more types of ingredients under the premise of meeting budget and nutrient standards.

Definition of Constraints [9].
Constraints such as meeting the budget requirement and satisfying the daily nutrient requirement are as follows:

$$\begin{cases} \sum_{i=1}^{n} p_i x_i \le B \\ L_j \le \sum_{i=1}^{n} a_{ij} x_i \le U_j, \forall j \\ 0 \le x_i \le M_i y_i, \forall i \\ \sum_{i \in I_{\text{staple foods}}} y_i \ge 1, \quad \sum_{i \in I_{\text{meat dishes}}} y_i \ge 2, \quad \sum_{i \in I_{\text{vegetable dishes}}} y_i \ge 2 \\ x_i \ge 0, y_i \in \{0,1\} \end{cases}$$

Among them, p_i represents the unit price of ingredient i ; a_{ij} denotes the content of the j th nutrient in the i th ingredient; B stands for the maximum budget limit; L_j and U_j refer to the recommended intake range of nutrient j; M_i indicates the maximum reasonable intake of ingredient i. $I_{\text{staple foods}}$ represents the set of staple foods, $I_{\text{meat dishes}}$ represents the set of meat dishes, and $I_{\text{vegetable dishes}}$ represents the set of vegetable dishes. y_i=0 means ingredient is not selected, and y_i=1 means ingredient is selected. $x_i \ge 0$ indicates that the quantity of ingredient is non-negative.

Model Solution

It is known that i=1,2,...,13 correspond to the quantities of the 13 selected ingredients: rice, standard flour, corn, tofu, egg, chicken breast, lean pork, dried tofu sheets, chicken liver, tilapia, green pepper, broccoli, and spinach. The values corresponding to these 13 ingredients (prices and nutrient contents), nutrient intake levels, and the total budget amount B are substituted into the model, where the three categories of ingredients are defined as: staple foods $y_1+y_2+y_3 \ge 1$, meat dishes $y_6+y_7+y_9+y_{10} \ge 2$, vegetable dishes $y_4+y_5+y_8+y_{11}+y_{12}+y_{13} \ge 2$.

The model established in Section 3.2.1 is a mixed-integer nonlinear programming (MINLP) problem, which is a complex optimization task involving both integer and continuous variables as well as nonlinear constraints. To simplify the solution process, the objective function can be processed through piecewise linearization—this converts the original problem into a mixed-integer linear programming (MILP) problem, after which a global optimal solution can be obtained using professional solvers (e.g., Gurobi). This paper only presents the modeling framework and feasible solution methods for the nonlinear programming model, without elaborating on specific numerical solutions. Future research can integrate real canteen operation data, conduct numerical experiments using the aforementioned tools, and further verify the model's validity and applicability.

Conclusion and Outlook

Focusing on the optimization of nutrition and cost for campus canteen nutritious meals, this study constructs an optimization model for campus nutritious meals based on the Dietary Guidelines for Chinese Residents (2022) and Dietary Reference Intakes (DRIs). First, under the linear programming framework, with the goal of minimizing costs, the optimal ingredient combination is obtained on the premise of meeting the daily core nutritional needs of middle school students. From the results, only three ingredients—corn, tofu, and spinach—need to be selected to meet the requirements of major nutrients such as protein, calcium, iron, and vitamin C, with the total cost controlled at 2.93 RMB. This shows that the model achieves a certain balance between nutritional balance and funding pressure. However, the solution results also reveal limitations. The ingredient selection of the minimum-cost solution is excessively single, excluding ingredients such as meat and eggs. It cannot meet the practical demand for "a mix of meat and vegetables and diversity" in campus meals, and may affect students' taste acceptance and long-term nutritional balance. To address this, this study further proposes adding ingredient type constraints to the model and introducing a nonlinear utility function to construct a mixed-integer nonlinear programming model. This aims to encourage ingredient diversity and make the solution more in line with actual meal supply standards. At the same time, this study also has certain limitations: the model fails to fully consider practical complexities such as price fluctuations, seasonal supply of ingredients, and differences in students' tastes. Future research can be carried out in the following directions: Further expand the ingredient database, integrate long-term tracking data, and incorporate regional and seasonal differences to improve the model's universality and dynamic adaptability; Explore a multi-objective optimization framework that integrates cost control, nutritional balance, and taste acceptance into a unified model; Combine heuristic algorithms and intelligent optimization tools in methods to improve the solution efficiency for large-scale problems; Promote the integration of the model with campus catering management systems and develop an operable decision support platform.

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