Artificial Intelligence, Medical Engineering and Education
Z. Hu et al. (Eds.)

doi:10.3233/ATDE250127

Dietary Recipe Design of Single Objective Programming Based on Analytic Hierarchy Process

Yijia WANG[1], Yichen FENG, Ruikun FANG
Guohao college of Tongji University, Tongji University, Shanghai, China
ORCID ID: Yijia WANG https://orcid.org/0009-0002-0324-5946

Abstract. Mathematical modeling can optimize dietary plans, but relevant research is scarce. This paper adopts the Analytic Hierarchy Process (AHP) and single-objective optimization model in mathematical modeling. Based on the “Chinese Food Composition Table”, an evaluation model is constructed, and This paper is presented from the perspective of food structure, energy, meal ratio, nutrients, and protein amino acids. Through Matlab programming, the diet is optimized to maximize the protein amino acid score and reduce costs. The results show that single optimization is prone to imbalance or high costs, while comprehensive optimization achieves both balanced nutrition and economy. This scheme provides a scientific basis for dietary optimization and promotes the development of healthy diets.

Keywords. Dietary recipes; Protein amino acids; MATLAB programming software; Food ingredients.

1. Introduction

In current society, with the increasing pursuit of healthy life, the design of dietary recipes has not only satisfied the basic nutritional needs, but also tends to be personalized, scientific and refined. Scientific and rational development of healthy dietary recipes cannot only avoid the obesity problem faced by people, but also become a powerful starting point for promoting healthy life [1,2]. In the face of diverse food choices and complex nutritional needs, how to develop a dietary recipe that meets both nutritional balance and individual tastes has become an important research topic in the fields of nutrition, food science and health management.

The formulation and optimization of dietary recipes is a process of multi-dimensional consideration and trade-off. Its core is to ensure the balance and adequacy of various nutrient intakes, while taking into account individual taste preferences. This process not only requires the identification and evaluation of all key factors affecting dietary quality, but also requires continuous improvement of recipes using scientific methods to meet personalized health needs.

In order to solve the complex problems in the optimization of dietary recipes, this paper introduces the analytic hierarchy process (AHP) of single objective programming. By using the analytic hierarchy process of single objective programming to optimize the design of dietary recipes, it can not only provide more scientific and reasonable and

[1] Corresponding Author: Yijia WANG, E-mail: 2159024496@qq.com.

personalized dietary programs, improve the quality of diet and quality of life of the public, but also promote the development of nutrition and health, and contribute to the construction of a healthy society. In the future, with the continuous advancement of technologies such as big data and artificial intelligence, the optimization design of dietary recipes will be more intelligent and accurate, escorting everyone's health [3].

2. Literature Review and Research Hypotheses

2.1. Literature Review

In recent years, with the significant improvement of people 's living standards and the general enhancement of health awareness, dietary nutrition has become the focus of attention from all walks of life. Scientific and reasonable dietary recipes are not only the basis for maintaining individual health, but also the key to preventing obesity, chronic diseases and improving immunity. However, although the importance of dietary nutrition is self-evident, the existing research and practice are still insufficient in the optimization design of dietary recipes, and a more systematic and comprehensive method is urgently needed to guide the practical application.

Domestic research status. In China, the research in the field of dietary nutrition has achieved certain results, mainly focusing on the intake of single nutrients, the diversity of food types and the rationality of dietary structure. For example, a number of studies have shown that the proportion of carbohydrates, fats and proteins in the diet has a crucial impact on maintaining physical health and preventing diseases [4]. In addition, a variety of food types and a balanced dietary structure are also widely considered to be the key to ensuring a comprehensive nutritional intake. However, most of these studies remain at the level of theoretical discussion and unilateral factor analysis [5,6], lacking in-depth analysis of the actual dietary situation of the group and empirical research on optimization design. Therefore, although there is a certain theoretical basis, in practice, how to formulate scientific and reasonable dietary recipes according to the specific needs of individuals or groups is still an urgent problem to be solved.

International research trend. In contrast, the international research on dietary optimization design is relatively mature. Researchers often use advanced methods such as mathematical modeling and data analysis to design dietary recipes considering various factors [2, 7,8]. For example, the Analytic Hierarchy Process (AHP) is used to determine the weights of dietary evaluation criteria, and then the dietary recipe is improved through an optimization model to obtain an optimization plan that meets the needs of specific populations [9,10]. Its purpose is not only to improve the scientificity and accuracy of dietary design, but also to make dietary plans closer to actual needs. At the same time, it is necessary to detect and ensure the safety and reliability of food through traceability systems and blockchain technology [11-13]. It is worth noting that these international studies may face some degree of adaptability issues when applied to specific dietary needs, especially when there are differences in cultural backgrounds, dietary habits, and other aspects [14, 15]. Continuously improving the quality of the food supply chain is a persistent task [16].

Deficiencies in existing research. Despite the progress made in dietary nutrition research both domestically and internationally, there are still many deficiencies. Especially for the diets of Chinese people, there is a lack of comprehensive, systematic, and operable dietary optimization design methods. On the one hand, domestic research mostly focuses on theoretical exploration and unilateral factor analysis, lacking systematic optimization design methods; on the other hand, although international research methods are advanced, there may be adaptation issues in specific applications. Therefore, how to develop a scientific and practical dietary optimization design method that combines the dietary characteristics and actual needs of Chinese people has become an important issue that needs to be addressed urgently.

The purpose and significance of this study. Given the above background, this paper aims to design dietary recipes that meet the dietary needs of Chinese people while considering both nutrition and economy by introducing advanced methods such as the Analytic Hierarchy Process (AHP) and optimization models, combined with actual dish data from canteens. Specifically, this paper will first analyze the dietary characteristics and nutritional needs of Chinese people, then use the AHP to determine the weights of dietary evaluation criteria, and finally improve and optimize the dietary recipes through optimization models. Through this research, it can not only provide new perspectives and methods for theoretical research in the field of dietary nutrition but also provide scientific and practical guidance for dietary design in real life, thereby promoting the improvement of healthy eating among Chinese people.

2.2. Research Hypotheses

Based on the above literature review, the following research hypotheses are proposed in this paper:

H1: Dietary optimization design can effectively improve the nutritional level of diets: By introducing the Analytic Hierarchy Process (AHP) and optimization models, dietary recipes can be designed that excel in food structure, energy sources, content of non-productive essential nutrients, and protein amino acid scores, thereby effectively enhancing the nutritional level of diets.

H2: Both economy and nutrition can be achieved simultaneously: In the process of optimizing dietary recipes, through rational selection of ingredients and dishes, it is possible to economize meal costs while ensuring dietary nutrition, thereby satisfying the financial affordability of individuals.

H3: The dietary optimization design plan needs to consider the actual needs of the group: When designing the dietary optimization plan, factors such as individual dietary habits, taste preferences, and nutritional needs should be fully considered to ensure that the designed dietary recipes are both scientifically reasonable and easily accepted.

Through the validation of these research hypotheses, this paper aims to provide a set of operational and practical methodological systems for the optimization design of dietary nutrition, contributing to the improvement of the dietary nutrition level of the population.

3. Construction of a Scoring Model for Dietary Nutrition Coefficients

Currently, domestic literature on dietary recipe research primarily remains at the level of theoretical discussion and unilateral factor analysis, with limited in-depth modeling analysis for a comprehensive evaluation system of dietary recipe nutrition. To address this, this paper employs a single-objective Analytic Hierarchy Process (AHP) to construct a scoring model for recipe nutrition coefficients. It decomposes various factors influencing dietary quality (such as nutrient intake, ingredient variety, taste preferences, etc.) into a target layer, criterion layer, and scheme layer. Based on nutritional principles, it sets a general goal of achieving nutritional balance and clarifies various criteria (e.g., the intake ranges of protein, fat, carbohydrates, etc.) that influence the realization of this goal. The AHP's comparison matrix is utilized to calculate the weights of each criterion, reflecting their degree of importance in the diet. Ultimately, based on the weight distribution, a comprehensive evaluation of existing recipes is conducted, and a single-objective programming model is applied to adjust parts that do not meet standards or can be optimized, thereby enhancing the overall quality of the recipes.

3.1. Indicator Selection and Analysis

In this paper, four indicators are selected as the evaluation criteria for the evaluation model. The specific contents of these four indicators and their numerical representation are as follows:

a. Food structure. The foods in the recipe are sorted and counted by category to confirm whether they encompass the five major food groups: grains and potatoes, vegetables and fruits, meat, eggs, beans, and milk, oils and fats, and aquatic products. Additionally, it is verified whether the variety of food items reaches 12, as the standard for a plan is at least 25 different food items. This serves as an evaluation criterion to ensure dietary diversity and balance.

b. Energy provided by the recipe, meal ratio, and content of non-energy-yielding macronutrients. This evaluation process is grounded in the preset daily energy intake target and the reasonable proportion of energy allocation b meals. Furthermore, it considers whether the content of non-energy-yielding macronutrients in the recipe, such as calcium, iron, zinc, vitamin A, vitamin B1, vitamin B2, and vitamin C, meets the recommended intake levels. This assessment ensures that the diet provides energy while also fulfilling the body's requirements for various essential nutrients.

c. Energy sources of the recipe. The assessment of energy sources in the recipe involves comparing the proportions of energy contributed by carbohydrates, fats, and proteins to the total energy, checking if they align with the recommended proportions of macronutrient energy contributions.

d. Protein amino acid score per meal. Calculating the protein amino acid score for each meal's recipe evaluates the quality of the protein in the food. A score below 60 indicates an unreasonable amino acid composition of the protein; a score 60 to 80 is considered less than optimal; a score of 80 to 90 is relatively reasonable; and a score exceeding 90 is deemed a reasonable source of protein.

3.2. Establishment of the Evaluation Model

When evaluating the rationality of dietary nutrition, it is necessary to comprehensively consider the following four factors: food structure (factor a), energy provided by the recipe, meal ratio, and content of non-energy-yielding macronutrients (factor b), energy sources of the recipe (factor c), and protein amino acid score per meal (factor d). Based on these four indicators, a multi-level analysis model is established. All nutrient reference data for various food components can be queried from the book "Chinese Food Composition Table 2002", and the three daily meals are evaluated according to the evaluation criteria a, b, c, and d. The solution results of the model are used as the evaluation of dietary nutrition, as shown in Figure 1.

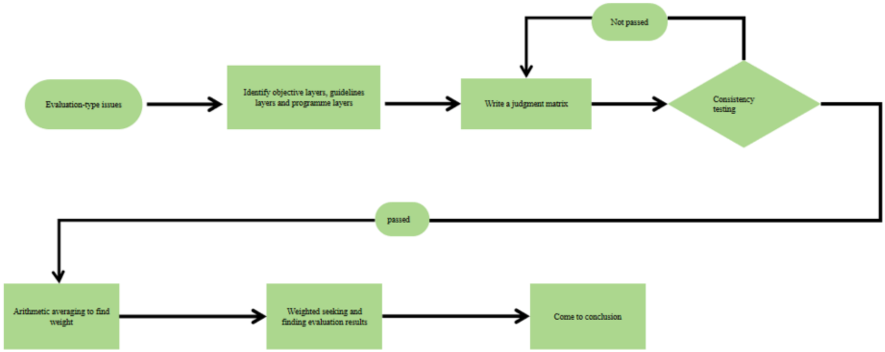

Figure 1. Flowchart of Model Establishment Thought Process

(1) Maximizing protein amino acid score as the objective. This paper establishes a linear programming model to list out the dietary plans that meet the nutritional requirements. By referring to the “Dietary Guidelines for Chinese Residents (2022)”, This paper understands the basic principles of meal planning, including the reasonable range of meal ratios and the reference range of total energy intake for both male and female students. Using MATLAB programming. This paper screens out all the dietary plans that meet the constraints. Among these plans. This paper applies the programming model and Monte Carlo method to identify the plan with the highest protein amino acid score. Taking into account factors such as food repetition and the balance of meat and vegetables. This paper finally determines the most suitable plan. Subsequently. This paper conducts an evaluation and analysis of this plan.

(2) Minimizing meal costs as the objective. Based on the dietary plans filtered out in (1) that meet the constraints. This paper uses the Monte Carlo method and programming model to find the plan with the cost. By considering factors like food repetition and the balance of meat and vegetables. This paper identifies the most suitable plan that aligns with this objective. Following that. This paper employes the optimization evaluation model established in the first question to evaluate and analyze this plan.

(3) Balancing the maximization of protein amino acid score and minimization of meal costs. To achieve both the maximization of protein amino acid score and the minimization of meal costs. This paper adopts the ideal point method in multi-objective linear programming to address this problem. Firstly, this paper acknowledges that the two objectives cannot be fully satisfied simultaneously, as evident from questions (1) and (2). Therefore, this paper uses the optimal values of the two single objectives as ideal values for the respective targets. Our goal is to minimize the squared sum of the differences between the two objective function values and their ideal values.

$$G = \min \sum_{k=1}^{m} \left[\omega_1 \left(P_k - P \right)^2 + \omega_2 \left(Q_k - Q \right)^2 \right] \tag{1}$$

Matlab programming was used in this paper. This paper obtains the optimal plan and subsequently conducts an evaluation and analysis of this plan.

3.3. Evaluation Model Solution and Analysis

(1) With the objective of maximizing the protein amino acid score. Matlab programming was used in this paper, software to initially screen out all possible daily meal plans that satisfy the constraint conditions. Then, based on the objective function, this paper ran Matlab to obtain a set of daily meal plans with the highest protein amino acid score. Taking into account factors such as food repetition and the balance of meat and vegetables, this paper evaluated whether to adopt this plan. If it was overly unreasonable, such as having two servings of mixed tofu for breakfast or no meat dishes for the entire day, this paper excluded this plan from the original data. This paper then repeated the above steps using Matlab programming software until This paper finally obtained a relatively reasonable daily meal plan designed with the objective of maximizing the protein amino acid score (unless specifically noted, all food items are served in one portion). The protein amino acid score for this meal plan is 10.39:

Breakfast: Rice porridge, mixed tofu, egg pancake;

Lunch: Egg pancake, pie, braised pork ribs, pot-coated pork slices;

Dinner: Steamed dumplings, egg pancake, dry-fried yellow croaker.

Using the evaluation model established in the first question, this paper obtained the scores for the four indicators of the optimized daily meal plan, shown as table 1.

Table 1. Scores of the Four Indicators for the Optimized Meal Plan

Indicator	a	b	c	d
Indicator Score	50	86.64	55.36	100
Weight	0.09	0.46	0.18	0.27

Therefore, the dietary nutrient score for this daily meal plan is:

$$0.09\times50+0.46\times86.64+0.18\times55.36+0.27\times100=81.32.$$

This indicates that the daily meal plan is relatively reasonable but still has some shortcomings, such as:

This meal plan lacks completeness in the five major food categories, specifically the absence of “dairy, dried beans, nuts, seeds, and their products,” resulting in a score for the indicator (food structure).

Since this meal plan was optimized with the objective of maximizing the protein amino acid score, it overlooked the energy factor derived from fat intake, leading to a higher content of meat components in the daily meal plan and excessive fat intake, which in turn resulted in a score for the indicator (energy sources of the meal plan).

(2) With the objective of minimizing meal expenses. Matlab programming was used in this paper, software to initially screen out all possible daily meal plans that satisfy the constraint conditions. Then, this paper ran MATLAB to obtain a set of daily meal plans with the meal expenses, costing 22.5 yuan:

Breakfast: Pan-fried stuffed buns, fried dough sticks, millet porridge;

Lunch: Chinese chive boxes, soybean milk, mixed tofu, stir-fried mushrooms with rape;

Dinner: Mixed spinach, chicken noodle soup, mixed tofu.

Next, as table 2 shows, using the evaluation model established in the first question, this paper obtained the scores for the four indicators of the optimized daily meal plan:

Table 2. Scores of the Four Indicators for the Optimized Daily Meal Plan

Indicator	a	b	c	d
Indicator Score	50	75.47	73.19	86.71
Weight	0.09	0.46	0.18	0.27

Therefore, the dietary nutrient score for this daily meal plan is:

$$0.09\times50+0.46\times75.47+0.18\times73.19+0.27\times86.71=75.80.$$

This daily meal plan is relatively unreasonable, with the following issues:

1.The five major food categories are incomplete in this meal plan, lacking "dairy, dried beans, nuts, seeds, and their products," resulting in a score for indicator a (food structure).

2.Since this meal plan was optimized with the objective of minimizing meal expenses, there is an imbalance in the intake of non-energy-yielding nutrients, such as severe deficiencies in calcium and vitamin C, leading to a score for indicator b (score for the energy provided by the meal plan, meal ratio, and content of non-energy-yielding nutrients).

(3) Balancing maximum protein amino acid score and minimum meal expenses. From the solutions of (1) and (2), This paper obtains the ideal values of the two single-objective functions as 10.39 and 10.19, respectively. Since maximizing the protein amino acid score and minimizing meal expenses are equally important, this paper assign equal This paper of 0.5 to both, and Equation (1) can be simplified as:

$$H=\min\sum_{k=1}^{m}\left[\left(P_k-P\right)^2+\left(Q_k-Q\right)^2\right] \tag{2}$$

This represents the optimal value of the evaluation function.

(4) Balancing maximum protein amino acid score and minimum meal expenses. From the solutions of (1) and (2), This paper obtained the ideal values of the two single-objective functions as 10.39 and 10.19, respectively. Since maximizing the protein amino acid score and minimizing meal expenses are considered equally important, This paper assign. ω_1 and ω_2 assign equal This paper to both 0.5, Equation (1) can be simplified as:

$$H=\min\sum_{k=1}^{m}\left[\left(P_k-P\right)^2+\left(Q_k-Q\right)^2\right] \tag{3}$$

This represents the optimal value of the evaluation function.

Matlab programming was used in this paper, software to initially screen out all possible daily meal plans that satisfy the constraint conditions. Then, based on Equation (3), Matlab programming was used in this paper, software to obtain a set of daily meal plans that balance both maximizing the protein amino acid score and minimizing meal expenses:

Breakfast: Millet porridge, mixed tofu, mixed tofu;

Lunch: Steamed dumplings, pies, pies;

Dinner: Stir-fried mushrooms with rape, egg cakes, egg cakes, mixed tofu.

Next, this paper applied the evaluation model established in the first question to obtain the scores for the four indicators of the optimized daily meal plan, presented as table 3.

Table 3. Scores of the Four Indicators for the Optimized Daily Meal Plan

Indicator	a	b	c	d
Indicator Score	50	84.40	40.83	100
Weight	0.09	0.46	0.18	0.27

Therefore, the dietary nutrient score of this daily meal plan is:

$$0.09\times50+0.46\times84.40+0.18\times60.83+0.27\times100=81.27.$$

Due to the simultaneous consideration of maximizing the protein amino acid score and minimizing economic costs, this daily meal plan is relatively unreasonable, with the following issues:

1) This meal plan lacks completeness in the five major food categories, specifically the absence of "dairy, dried beans, nuts, seeds, and their products, resulting in a score for the indicator (food structure).

2) Since maximizing the protein amino acid score and minimizing meal expenses are equally important in this daily meal plan, it has compromised dietary quality. There is a high degree of repetition in the meals, and there is virtually no meat, leading to insufficient fat intake. This results in an excessively low score for the indicator (energy sources of the meal plan).

4. Conclusion

This study takes food delivery riders as the research subjects to explore the influential mechanism of perceived algorithmic control on counter-algorithmic behaviors. The following research conclusions have been drawn:

Firstly, a daily meal plan is designed with the goal of maximizing the protein amino acid score. This meal plan excels in protein intake, fully reflecting its emphasis on enhancing protein quality and meeting the body's amino acid requirements. Protein is a crucial component of human tissues and an indispensable nutrient for maintaining life activities. Such meal plans designed through optimization models can ensure adequate daily protein intake and balanced amino acid ratios, which are conducive to growth, repair, and immune functions of the body. In this paper, such meal plans also have potential issues, notably the potential for excessive fat intake. While fat is an essential nutrient, its excessive consumption increases health risks such as cardiovascular diseases and obesity. Therefore, while striving for a high protein amino acid score, it is crucial to also focus on reasonable control of fat intake.

Secondly, a daily meal plan is designed with the goal of minimizing meal expenses. Such meal plans offer low economic costs, making them highly appealing to consumers with limited budgets. By optimizing ingredient selection and cooking methods, these plans can reduce meal expenses while ensuring basic nutritional needs. These meal plans have the paper dietary nutrient scores, indicating inadequate intake of non-energy-producing nutrients like vitamins and minerals. These nutrients play vital roles in maintaining normal physiological functions and preventing diseases. Therefore, long-term consumption of such meal plans may lead to nutritional imbalances and impact health.

Lastly, a daily meal planes that balances both maximizing the protein amino acid score and minimizing meal expenses is also designed. To balance protein quality and economic costs, the study has crafted meal plans that find a certain equilibrium between these two objectives. These mseal plans guarantee high-quality protein intake while striving to control meal expenses. due to the need for trade-offs the two goals, these meal plans may suffer from issues like high dietary repetition and potential nutritional imbalances. Repetitive dietary patterns can lead to deficiencies or excesses of certain nutrients, thereby affecting health.

References

[1] Wang Guangya. China's new food composition table[J]. Beijing, Institute of Nutrition and Food Safety, Chinese Center for Disease Control and Prevention, 2000 (in Chinese).
[2] Rastogi, Yash Raj, Thakur, Rahul, Thakur, Priyanka, et al. Food fermentation-significance to public health and sustainability challenges of modern diet and food systems[J]. International Journal of Food Microbiology, 2022, 371.
[3] Santagelo C, Mandracchia F, Bondi D, et al. Traditional dishes, online tools, and public engagement: A feasible and scalable method to evaluate local recipes on nutritional content, sustainability, and health risks. Insight from Abruzzo, Italy[J]. Journal of Food Composition and Analysis, 2022, 114.
[4] Li Shujuan, Xu Xiaoli, Yu Dongmei, et al. Study on dietary intake characteristics and regional differences of Chinese farmers from 2010 to 2012[J]. China Food and Nutrition, 2021, 27 (6): 82-88 (in Chinese).
[5] Gu Hua, Mi Mantian, Zhao Yongguang et al. Preliminary study on the application of analytic hierarchy process in the evaluation of nutritional diet in Chinese adults[J]. China Health Statistics, 2009, 26(4): 391-393 (in Chinese).
[6] Liu Peng. Analysis of the changing trend and influencing factors of dietary structure of Chinese residents-A study based on CHNS database[D]. Xi'an: Shanxi University of Finance and Economics, 2016 (in Chinese).
[7] Kehlet U, Chrisensen L, Raben A, et al. Physico-chemical, orosensory and microstructural properties of meat products containing rye bran, pea fibre or a combination of the two[J]. International Journal of Food Science and Technology, 2020, 55(3): 1010-1017.
[8] Jaohong Cheng, Shuwei Chen. A Fuzzy Delphi and Fuzzy AHP Application for Evaluating Online Game Selection[J]. International Journal of Modern Education & Computer Science, 2012, (5): 7-13.
[9] Epelbaum F M B, Martinez M G. The technological evolution of food traceability systems and their impact on firm sustainable performance: A RBV approach[J]. International Journal of Production Economics, 2014, 150(4):215-224.
[10] Sudo, Noriko, Perry, Courtney, Reicks, Marl. Adequacy of dietary intake information obtained from mailed food records differed by weight status and not education level of midlife women[J]. Journal of the American Dietetic Association, 2010, 110(1): 95-100.
[11] Zhai Fengying, Wang Huijun, Du Shufa, et al. Tracing the changes of dietary structure and nutritional status of Chinese residents[J]. Journal of Medical Research, 2006, 35(004): 3-6 (in Chinese).
[12] Vedant Sharma, Anitha Palakshappa, Syed Adil Naqvi. Enhancing traceability in agricultural supply chain using blockchain technology[J]. International Journal of Information Engineering and Electronic Business, 2024, 16(3): 11-21.
[13] A.S.M. Fazle Rabbi, T.M. Ragib Shahrier, Md. Mushfiqur Rahman Miraz et al. Beyond the hype: a proposed model based on critical analysis of blockchain technology's potential to address supply chain issues[J]. International Journal of Information Technology and Computer Science, 2023, 15(6): 50-64.
[14] Huang Gangping. Diet Nutrition and Hygiene[M]. Sichuan University Press, 2003 (in Chinese).
[15] Sun Xiuyan. Dietary guidelines for Chinese residents[J]. Food Industry, 2022, (06): 22-24 (in Chinese).
[16] Thitirath Cheowsuwan, Sudarat Arthan, Supan Tongphet. System design of supply chain management and Thai food export to global market via electronic marketing[J]. International Journal of Modern Education and Computer Science, 2017, 9(8): 1-8.