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Research Article

# Incorporating A Hybrid Fuzzy Logic Model in Diet Style Selection

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**ABSTRACT**

The decisions and emotions of people are highly influenced by food pattern which plays a vital role in their daily activities. Dieting patterns differ in terms of the goals set by a certain individual. People are advised to know how to regulate their diets and select eating habits that will promote health by preventing food-related diseases. Six diet styles were evaluated and ranked by considering multiple important factors utilizing a multi-criteria decision-making algorithm; the fuzzy Preference Ranking Organization Method for Enrichment Evaluations (fuzzy PROMETHEE). Of all considered diet styles, the low-carb diet ranked first diet style with a net flow of 0.2066, and the intermittent diet ranked sixth with a net flow of -0.3232; however, depending on the chosen criteria and assigned weights, the outcomes would change dramatically when weights are modified according to the specific person's profile. This study will help individuals, dieticians, and nutritionists make appropriate diet plans by choosing which pattern to follow with awareness of the probable risk and consequences associated with their choice.

## 1. INTRODUCTION

Regimen takes on a central role in the thoughts and emotions of dieters, which results in dietary limitations, an overemphasis on food-related issues, a lack of pleasure in food, the ability to manage one's intake of food, and inflexible eating habits [1], [2], [3]. When there is no motivation to reduce weight, habits may occasionally be linked to unintended weight reduction which can cause several diseases and increase the prevalence rate of diverse comorbidities. Furthermore, even if they are not hungry immediately, individuals who are worried about starvation may be more inclined to consume food in an attempt to avoid being hungry, this is likely to result in more food consumption and a less regular dieting style [4]. The health-related advantages of a diet have been demonstrated in several studies and controlled clinical trials; more

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on this is found in [5]. Vitamins, proteins, carbohydrates, and fats in food have to be well-controlled in terms of intake when it comes to a particular diet pattern [6].

Among the most important nutritional elements that affect the emergence of various chronic disorders is diet. People ought to understand how to regulate their diets and select eating habits that will promote health and fight against diseases that are connected to food. For many years, nutrition science has examined how one essential element affects health, and from this, more interest in overall dietary patterns as a result of a recent understanding of the intricate synergistic connections between nutrients and other food components has emerged in the research world. Therefore, the phrase "dietary patterns" has come to represent a far more comprehensive examination of food and nutrient intake [7]. Dietary patterns are more informative regarding the predisposition to develop certain ailments, especially cardiovascular or cerebrovascular diseases due to the complicated system of interactions between the genome and epigenetic variables. That is how the patterns of diet identified by the means of nutrition cluster analysis might approximate the danger posed by a specific disease or even the probability of death [8]. Dietary pattern analysis has proved to be an effective and promising mechanism in the evaluation of the impact of food on the risk of developing severe health conditions in the past 10 years. The studies conducted on the dietary pattern are receiving an increased attention to nutrition policy due to its high rate of supporting the use of a balanced diet in promoting health [7].

The most common diets in the Western world include: the Mediterranean diet, strategies used to prevent high blood pressure, the Paleolithic diet, the low-carb and low-fat diets, and the plant-based diets [9], [10], [11]. Diets low in carbohydrates have been advocated and utilized all over the world to cure diabetes and control weight [12]. Even though iodine cannot be obtained from CHO-rich meals, the Atkins and "Paleolithic" diets forbid milk and dairy products, resulting in a decreased intake of iodine [12]. From the benefits and various drawbacks of diverse diet styles, it is still challenging for most people to choose which type of diet plan they will follow that is less likely to cause health issues and yet advantageous to the person. This study aims to evaluate six diet styles (low-carb, paleolithic, plant-based, Mediterranean, vegetarian, and intermittent dietary modes) and ranks them by weighing various important criteria (cardiovascular disease reduction, lowering blood pressure, weight loss, cost, carbohydrate, fats, protein, and calories intake, as well as constipation) using a multi-criteria decision-making algorithm, specifically, the fuzzy Preference Ranking Organization Method for Enrichment Evaluations (fuzzy PROMETHEE). Among the few scientists who have used fuzzy PROMETHEE are [13], [14], [15], [16], [17]. The effectiveness and robustness of this approach will help in making concrete nutritional decisions for patients or even personal use.

The remaining body of the paper is organized as follows: section 2 introduces the considered diet styles and methodology used, section 3 introduces results which are further discussed in section 4 and finally the study is concluded in section 5.

## 2. MATERIALS AND METHODS

### 2.1 Diet Styles

#### 2.1.1. Intermittent Diet

The phrase "intermittent fasting" refers to a nutritional pattern in which people timely alternate fasting and consuming calories. The majority of research has been on physiological modifications, emphasizing advantages like weight loss, a reduction in body fat, and enhancements in cardiovascular indicators. Weight loss and adjustments in glycemic control were cited as noteworthy results in a comprehensive evaluation of the literature by Welton et al. [18]. They concluded that intermittent fasting offers the potential for managing obesity. In addition, in their analysis, Malinowski et al. [19] revealed that intermittent fasting reduces the probability of acquiring cardiovascular illnesses by lowering risk variables. Furthermore, it has been proposed that intermittent dieting has good cognitive side effects [4].

#### 2.1.2. Vegetarian Diet

Nowadays, vegetarianism in all of its varieties has gained popularity. The elimination of particular food groups from the diet distinguishes the various types of vegetarianism [20]. This type of regimen is primarily linked to moral and religious principles, environmental concerns, cultural values, as well as social values. Depending on the daily intake of fruits, veggies, cereals, nuts, and grains [21], as well as the fact that vegans tend to lead healthier lifestyles than people who follow other types of diets [22], a vegan diet possesses many positive impacts on health. A decreased incidence of non-communicable illnesses has been mentioned as one of these health benefits [23], [24]. The typical vegan diet is currently a well-known healthy eating style, and it is an effective strategy for managing the risk of cardiovascular disease, including hypertension, diabetes, and hypercholesterolemia [25], [26].

#### 2.1.3. Low-Carb Diet

A low-carb diet pattern is the most efficient method to reduce weight and also has positive health effects including lowering blood pressure and decreasing cholesterol levels. Though low-carb diets may be advantageous for certain individuals, they are not the ideal choice for everyone looking to reduce their weight [27]. The United States Department of Agriculture (USDA) has suggested that from the 1970s, the majority of daily calories come from carbs, such as bread, pasta, and cereals, with a modest intake of proteins and little intake of fats. Low-carb regimens are the most effective for losing weight, but their unique properties must be evaluated with other long-term health effects. As a result, people who are thinking about adopting a low-carbohydrate strategy to lose weight must be warned of the hazards involved [27].

#### 2.1.4. The Mediterranean Diet

The Mediterranean diet has, over the years, been regarded as the diet of a poor man, as people have fought hard to produce food in environments that are not conducive. The defining characteristics of this diet include a moderate intake of red wine, moderate intake of fish, poultry, and dairy foods, and low intake of red meat and sweets. Fruits, root vegetables, grains, legumes, nuts, seeds, and olive oil, are also included [8]. This

diet was added to the UNESCO Intangible Cultural Heritage in 2010 [7]. A negative correlation is reported [28], [29] between the Mediterranean diet style and the occurrence of coronary artery disease.

### 2.1.5. The Paleolithic Diet

The Paleolithic diet (PD) is an eating plan patterned on meals prominent throughout the Old Stone Age. It primarily consists of eating lean meat, fish, eggs, fruits, vegetables, roots, and nuts and avoids grains, dairy products, processed food, added sugar, and salt [30]. Although they contain more protein and other micronutrient levels, including vitamins C and E, carotenes, and fiber, this dietary pattern has lower salt levels and reduced calorie consumption from carbohydrates and refined fat [31], [32], [33]. Moreover, previous studies discovered that PD positively influenced calorie intake, body mass, insulin sensitivity, and cardiovascular disease predictors [30], [34], [35]. Additionally, an increased concentration of phytochemicals present in the PD pattern reduces inflammation [36]. Even though PD has been shown to reduce risk factors for metabolic syndrome [37], there is a lot of disagreement on the therapeutic advantages of this dietary pattern. These debates also surround other cardiovascular disease risk variables, including blood pressure and lipid profile [30], [34]. In summary, there is much variation in how contemporary PD is understood [38] and more clarity is needed to better apply this diet style.

### 2.1.6. Plant-Based Diets

Plant-based diet (PBD) patterns are mostly rich in fruits and vegetables and characterized by high contents of fiber, phytochemicals, antioxidants, and omega-6 fatty acids [39]. Different types of diet are considered to be among the PBD category, including those that forbid eating meat and fish but permit the consumption of milk, dairy products, and eggs, as well as those that prohibit the consumption of any food of animal origin [40], [41]. Both the general public and the scientific community have become more interested in PBD over the past few years because it is now one of the primary dietary patterns used in Western nations [42]. According to the most recent research, PBDs are linked to a much lower risk of developing cardiovascular diseases and cancer [12]. The body mass indices, total cholesterol, low-density lipoprotein cholesterol, triglycerides, and blood glucose levels of dieters following a PBD tend to be lower [43], [44], [45], [46]. The possibility of acquiring undernutrition is the greatest drawback of this dietary pattern.

## 2.2 Fuzzy PROMETHEE Technique

This approach was created by [47], [48] and is founded on the mutual evaluation of each pair of alternatives concerning chosen concerning chosen criteria. When evaluating how the values of criteria contribute to each specific alternative, the PROMETHEE technique needs two forms of information: the weights of the criteria considered and the preference function of the decision-maker [49]. In daily life activities, it is frequently challenging to get the precise data necessary for accurately defining an issue and reaching the best decision. As a result, the decision-maker can identify the issue under vague circumstances by using fuzzy sets [50]. The hybridization of fuzzy logic and PROMETHEE has been primarily used for the assessment of two fuzzy sets. This hybrid mechanism is entitled fuzzy PROMETHEE.

## 2.3 Fuzzy PROMETHEE in Diet Style Evaluation

In this study, the Gaussian preference function was used to measure the level of preference of each alternative. The preference function (Pj) determines the degree of preference of an alternative $a_t$ above

another $a_{t'}$ that varies between 0 and 1. The PROMETHEE analysis involves the collection of the criteria, the computation of a preference function that is denoted by $P_j(d)$ where each criterion is indicated by the j, and the weight of that criterion is represented by a vector $w_T = (w_1, w_2, \dots, w_k)$ where $j \in (1, \dots k)$. In the case where the relative importance of the criterion is the same, the weights can be equal. The choice of the preference indices of the options $a_t \; and \; a_{t'} \in A$ has been formulated using $\pi$ and may be attained by applying Equation (1).

$$\pi(a_t, a_{t'}) = \sum_{k=1}^{K} w_k . \left[p_k\left(f_k(a_t) - f_k(a_{t'})\right)\right], \; AXA \rightarrow [0,1] \tag{1}$$

K refers to the criteria chosen and the preference index, denoted by $\pi \; (a, b)$ refers to the level of preference in the decision-making process. A data matrix, in Table I, was built based on numerous research studies on diet style [51], [52], [53], [54], [55], [56], [57], [58].

TABLE I. THE DATASET USED FOR EVALUATION

| | **Carbohydrate** | **Fats** | **Proteins** | **Calories** | **Cost ($)** | **Weight loss (pds)** | **Blood pressure reduction (mmHg)** | **Cardiovascular diseases REDUCTİON RATE (%)** | **Constipation** |
|---|---|---|---|---|---|---|---|---|---|
| **Plant-based** | 100-150 | 10-39 | 6.3 | 1,600-1,800 | 23 | 7.48 | -1.92 | 52 | No |
| **Paleolithic** | 150-300 | 40-50 + | 2.5 | 2,200 | 75 | 5-10 | -3.4 | 55 | Yes |
| **Mediterranean** | 20-60 | 35 | 9.0 | 1,527 | 53 | 1-2 | -0.7-1.5 | 50-70 | Yes |
| **Low-carb** | 20-70 | 70 | 1.5-2.0 | 1,500-2,000 | 59 | 5-10 | -1.6 | 77 | Yes |
| **Vegetarian** | 40-150 | 25-35 | 0.75 | 1,000-3,200 | 34 | 4.4 | -2.6 | 40 | No |
| **Intermittent** | >50 | 33 | 1.6-3.4 | 500-600 | 300 | 0-1.6 | -2-3 | 65 | Yes |

The calculations below are for the positive $\Phi^+(a_t)$ and negative $\Phi^-(a_t)$ outranking flows:

$$\Phi^+(a_t) = \frac{1}{n-1} \sum_{\substack{t'=1 \\ t' \neq t}}^{n} \pi(a_t, a_{t'}) \tag{2}$$

$$\Phi^-(a_t) = \frac{1}{n-1} \sum_{\substack{t'=1 \\ t' \neq t}}^{n} \pi(a_{t'}, a_t) \tag{3}$$

The number of alternatives is denoted as n where each alternative is compared to the rest of the alternatives (n -1) in the entire scheme. The positive outranking flow, which is denoted by $\Phi^{+}(a_t)$, is the strength of an alternative in $a_t \in A$. In contrast, the negative outranking flow, which is denoted by $\Phi^{-}(a_t)$, means the shortage of a substitute in $a_t \in A$.

In PROMETHEE I, alternative $a_t$ is better than alternative $a_{t'}$ $(a_t P a_{t'})$, provided that either of the following criteria is met:

$$\begin{cases} \Phi^{+}(a_t) > \Phi^{+}(a_{t'}) \; and \; \Phi^{-}(a_t) \leq \Phi^{-}(a_{t'}) \\ \Phi^{+}(a_t) = \Phi^{+}(a_{t'}) \; and \; \Phi^{-}(a_t) < \Phi^{-}(a_{t'}) \end{cases} \tag{4}$$

$a_t$ is said to be indifferent to $a_{t'}$ ( $a_t I a_{t'}$) when the alternative $a_t$ and the alternative $a_{t'}$ have the same positive and negative flows:

$$(a_t I a_{t'}) \text{ if: } \Phi^{+}(a_t) = \Phi^{+}(a_{t'}) \;\; and \;\; \Phi^{-}(a_t) = \Phi^{-}(a_{t'}) \tag{5}$$

Alternatives are difficult to evaluate on the basis of the functional criteria when one has more $\Phi^{+}(a_t)$ and more $\Phi^{-}(a_t)$ value, or when one has low $\Phi^{+}(a_t)$ and $\Phi^{-}(a_t)$ value. PROMETHEE I cannot be effectively used to analyzing similar cases.

$a_t$ is deemed distinct to alternative $a_{t'}$ $(a_t R a_{t'})$, when it satisfies any of the specifications listed below:

$$\begin{cases} \Phi^{+}(a_t) > \Phi^{+}(a_{t'}) \; and \; \Phi^{-}(a_t) > \Phi^{-}(a_{t'}) \\ \Phi^{+}(a_t) < \Phi^{+}(a_{t'}) \quad and \; \Phi^{-}(a_t) < \Phi^{-}(a_{t'}) \end{cases} \tag{6}$$

To deal with this issue, PROMETHEE II is applied as an alternative to PROMETHEE I offer a net outranking flow. As a result, the net flow to each alternative ($\Phi^{net}(a_t)$) is calculated as follows:

$$\Phi^{net}(a_t) = \Phi^{+}(a_t) - \Phi^{-}(a_t) \tag{7}$$

A final net flow-based ranking can be obtained using PROMETHEE II as illustrated below:

$a_t$ is preferred to $a_{t'}$ $(a_t P a_{t'})$ if $\Phi^{net}(a_t) > \Phi^{net}(a_{t'})$ (8)

$a_t$ is indifferent to $a_{t'}$ ( $a_t I a_{t'}$) if $\Phi^{net}(a_t) = \Phi^{net}(a_{t'})$ (9)

The greater its $\Phi^{net}(a_t)$ value, the better an alternative

Yager [59] found an index to find the magnitude of the fuzzy numbers depending on the center of weight of the membership function. The fuzzy numbers in this research were evaluated using the Yager index. In comparison to complex data, Brans et al. [47] explain that in the PROMETHEE, the weights of the criteria considered by the decision maker are to be determined besides the preference function. Consequently, in this analysis, the significance of alternatives was established using the linguistic scale in Table II. Then the Yager index was applied to establish the weight of all the criteria (cardiovascular disease reduction, lowering blood pressure, weight loss, cost, carbohydrate, fats, protein, and calorie intake, as well as constipation). The Gaussian preference function is thereafter chosen to compare the alternatives per criterion.

TABLE II. THE CONSIDERED FUZZY SCALE AND CHOSEN CRITERIA

| Linguistic scale for evaluation / Triangular fuzzy scale | Criteria |
|---|---|
| VH / (0.75,1,1) | Cardiovascular disease reduction, lowering blood pressure, weight loss, cost |
| H / (0.50, 0.75,1) | Carbohydrate intake, fats intake, protein intake, calorie intake |
| M / (0.25, 0.50, 0.75) | Constipation |
| L / (0, 0.25, 0.50) | - |
| VL / (0, 0, 0.25) | - |

(VH: Very High, H: High, M: Moderate, L: Low, VL: Very Low)

## 3. RESULTS

The low-carb diet style was the leading diet style among all the diet styles considered; as Table III has shown, the low-carb diet performed better with a net outranking flow of 0.2066 which was followed by the paleolithic diet with a net outranking flow of 0.1325, plant-based diet, the Mediterranean diet, and finally the vegetarian diet with the net outranking flows of 0.0499, -0.0194, and -0.0464 respectively. The intermittent diet was ranked the least with a net flow of -0.3232.

TABLE III. THE COMPLETE RANKING OF THE SIX CONSIDERED DIET STYLES

| Final Ranking | Diet styles | $\Phi^{net}$ | $\Phi^{+}$ | $\Phi^{-}$ |
|---|---|---|---|---|
| 1 | Low-carb diet | 0.2066 | 0.3927 | 0.1860 |
| 2 | Paleolithic diet | 0.1325 | 0.3485 | 0.2159 |
| 3 | Plant-based diet | 0.0499 | 0.3021 | 0.2522 |
| 4 | Mediterranean diet | -0.0194 | 0.2853 | 0.3047 |
| 5 | Vegetarian diet | -0.0464 | 0.2529 | 0.2993 |

| | | | | |
|---|---|---|---|---|
| 6 | Intermittent diet | 0.3232 | 0.1157 | 0.4389 |

$\Phi^{+}$: Positive outranking flow, $\Phi^{-}$: Negative outranking flow, $\Phi^{net}$: Net outranking flow

Figure 1 illustrates the positive and negative effects of the compared diet styles in the light of each of the selected criteria. Due to the sensitivity of fuzzy PROMETHEE, the decision maker can modify the criteria and the weight of each criterion, and he/she can explore the diet patterns with any criteria of interest. This change can result in different outcomes depending on the target of the study and the preference of the decision maker.

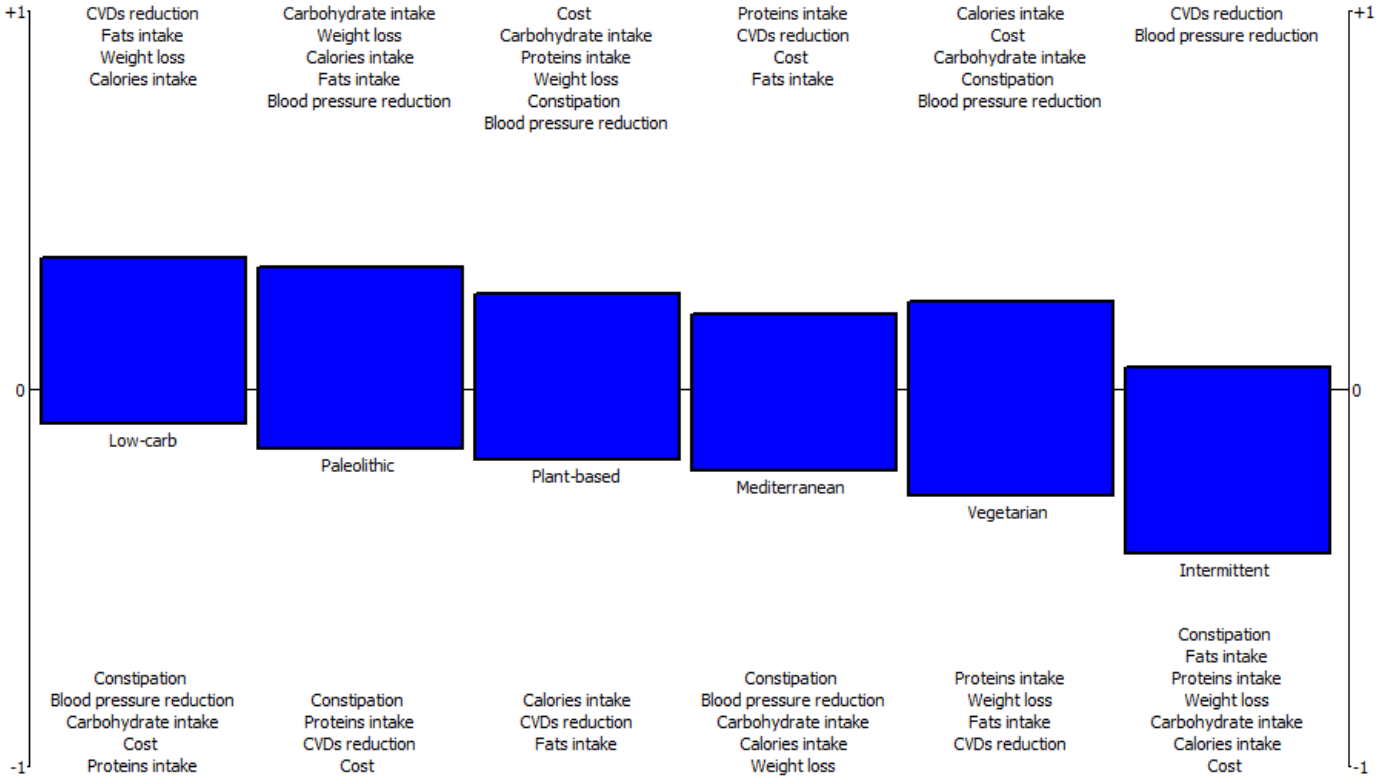


Fig. 1. PROMETHEE evaluation results

## 4. DISCUSSION

Non-communicable diseases affecting people in developed and underdeveloped countries are among the major mortality causes worldwide. Even though there are known biological and ecological risk factors for these health conditions, modifiable lifestyle-related parameters significantly impact the overall health status of people. For instance, dietary decisions raise the risk of high blood pressure, high cholesterol, obesity, and inflammation, which raises the risk of illnesses with high morbidity and fatality around the globe. Considering various health conditions that are caused by a low or excess intake of particular essential food components, starting a regimen brings several advantages as well as many disadvantages. Many people choose to start dieting because of diverse reasons; some want to reduce weight, others want to maintain their good health while others start a regimen prescribed by a specialized physician due to their health status

mostly for the minimization of risk associated with excess or deficiency in food consumption. For individuals with a target of lowering weight, a legitimate technique to lower weight is increased protein source consumption. Eating more protein suppresses appetite and increases satisfaction, which reduces calorie intake thus crucial for BMI reduction.

This study was conducted to evaluate various diet styles depending on numerous selected important criteria including cardiovascular disease reduction, lowering blood pressure, weight loss, cost, carbohydrate, fats, protein and calories intake, as well as constipation. Even though diets may reduce the incidence of obesity and cardiovascular disease risk, some diet styles, like vegetarian patterns increase the risk of nervous, skeletal, and immune system impairments, as well as hematological disorders due to low consumption of essential nutrients. On the contrary, though for some people, the low-carb diet style can be expensive depending on their financial status, this type of diet style has many benefits such as low risk of cardiovascular disease and diabetes, and it has most of the essential nutrients and enough calories that a person needs daily which rendered it to rank the 1$^{st}$ diet style in this study. Moreover, to avoid additional nutritional deficiencies and reduce any detrimental health effects, people should seek counsel from a dietician or other qualified medical practitioner regarding their nutritional status and any present symptoms. The main goal of this work was to rank diet patterns with minimal health risks, therefore, more studies with different targets such as weight loss or any other gap in nutrition science are still needed. Much more effort is required to incorporate these dietary mechanisms into everyday life all over the globe and to make healthy eating accessible, achievable, and sustainable. Moreover, low rates of food-related diseases can be achieved without drugs or pricey medical facilities.

## 5. CONCLUSION

Overall, implementing particular diet styles like consuming and/or avoiding some nutrients concurrently and consulting medical experts can assist people in meeting their target goals. In addition, the benefits and drawbacks of different diet styles vary, therefore individuals with interest should understand and be aware of the consequences associated with the diet before starting it. Most diet patterns have a high probability of lowering several health conditions. In this study with the target of analyzing and comparing six diet styles with fewer health risks, fuzzy PROMETHEE was used to rank the chosen alternatives depending on selected criteria. The low-carb diet style ranked as the first preferable, while intermittent fasting ranked sixth. Fuzzy PROMETHEE was highly effective in the ranking system, therefore, the results of this study can support and help individuals, dieticians, and nutritionists in making diet plans by choosing which pattern to follow with awareness of the probable risk and consequences associated with their choice.

### Author Contributions

All authors have contributed equally.

### Conflicts of Interest

The authors declare no conflicts of interest.

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The data used is provided within the manuscript.

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