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The Best Whey Protein Powder Selection via VIKOR Based on Circular Intuitionistic Fuzzy Sets

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Abstract: People try very hard to have a symmetrical, strong, and beautiful body. The human body needs high amino acids for muscle protein synthesis. Whey protein is a good choice that contains all amino acids, which increases muscle protein synthesis and improves body shape with resistance exercise. For this reason, those who do sports, especially professionals, prefer to use these products frequently. A large number of commercial whey protein powders are sold on the market, and to achieve maximum purpose, individuals want to use the best one. Intuitionistic fuzzy sets are used in order to minimize the negative effects of the uncertainty environment and ambiguous information encountered in the decision-making process on the solution. In this study, VIKOR, based on the circular intuitionistic fuzzy set, has been used to determine the best whey protein supplement. In line with the comprehensive literature review and expert opinions, the evaluation criteria affecting the selection process have been determined, and the solution of the problem has been focused.

Keywords: circular intuitionistic fuzzy set; decision making; VIKOR; whey protein; MCDM

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1. Introduction

Compared to the past, individuals are now more conscious about balanced nutrition and give importance to their bodies with regular exercise activities. The younger generation takes good care of themselves with regular exercise activity because of both a healthy life and social media sharing as well as visuality coming to the fore. For whatever purpose, individuals who undertake regular sports are also careful to consume foods and beverages with high protein content to develop their muscles, which are generally arranged symmetrically throughout the body. People give importance to physical activities along with nutrition, and for this reason, today, not only professional athletes but also ordinary individuals are trying to meet their high protein requirements with sports supplements. As a result, the demand for sports supplements has increased, and the market has grown [1,2]. While the essence of sports supplements is milk proteins, there are also minor levels of vitamins, minerals, essential fatty acids, some amino acids, and fibers. Milk powder obtained by drying fresh milk has become a traditional and common product due to its long shelf life and abundance. At the same time, powders with high protein content, which have become popular in recent years and obtained from whey, are preferred at increasing rates [3–5].

It is predicted that the global sports nutrition market will grow with the removal of the rules brought about due to pandemic conditions. The global whey protein market size is valued at USD 12.41 billion in 2022 and is expected to attain around USD 21.36 billion by 2032, growing at a compound annual growth rate (CAGR) of 5.58% from 2023 to 2032 [6].

Whey protein is a by-product of the cottage cheese and cheese casein manufacturing process. Since the disposal of the waste resulting from this production is a very costly process, manufacturers obtain dry, powdered whey protein from this by-product as a result of nanofiltration and ultrafiltration processes. Whey protein is very rich in calcium, potassium, phosphorus, magnesium, sodium, and lactose, which play an important role in mineral absorption. Whey protein also contains immunoglobin, glycomacropeptide, α-lactalbumin, and β-lactoglobulin. Due to this rich content, this product is extremely beneficial for individuals with cardiovascular problems. In addition, due to its antihypertensive and antibacterial properties, it is used in the food industry in bakery products, dairy products, beverages, cereals, chocolates, and baby foods [7].

Studies have reported that whey proteins increase athletic performance or improve physiological adaptations during training. There are studies showing that this product is the "Gold Standard" in terms of protein. Professional athletes, in particular, need twice the recommended daily amount of protein in their diet. The reasons why whey proteins are preferred can be listed as follows [8]:

- it is a food supplement that contains all the essential amino acids needed in daily life. It contains the ideal combination of amino acids that improve body composition and increase athletic performance;
- it contains high amounts of branched-chain amino acids. Since these amino acids are metabolized directly into muscle tissue, they are important for athletes in exercise and resistance training. They provide branched-chain amino acids, which are essential for rebuilding the body's missing and repairing lean muscle tissue;
- it is a good source of essential amino acids such as leucine. It is important for athletes because leucine plays an important role in supporting muscle protein synthesis and muscle growth. Studies have shown that those who do sports and have a diet high in leucine have more lean muscle tissue and less body fat than others [8].
- it is an easily soluble and digestible protein and is efficiently absorbed by the body. It provides nutrients to the muscles quickly.
- it increases the glutathione levels in the body of individuals and strengthens the immune system—glutathione is an antioxidant essential for a healthy immune system. Exercise and resistance training can cause a decrease in glutathione levels in the body; for this reason, when taking whey proteins, athletes increase their deficient glutathione levels and strengthen their immune systems.

Due to these benefits, fitness and sports clubs support their customers in using whey protein. However, individuals and athletes remain hesitant about which of the many products available in the market is more effective. This study has been prepared in order to scientifically support consumers in this decision-making problem. The basis of the study is to seek answers to questions such as "Which criteria should be considered when choosing whey protein?" and "Which of these commercially available products should be purchased?". This study was carried out because the answers to these questions do not have a counterpart in the literature. The outputs of this research will support fitness and sports club managers, individuals who regularly do sports, and professional athletes.

The problem under consideration is a typical multi-criteria decision-making problem. The criteria discussed in the problem and the identified alternatives will be evaluated by using scientific methods developed in the solution of multi-criteria decision-making problems. Due to the uncertainty and insufficient information, the selection criteria will be evaluated, and the best whey protein will be selected by using the VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje-Multicriteria Optimization and Compromise Solution) method based on circular intuitionistic fuzzy numbers in this problem. The VIKOR method is frequently used in the literature because it determines a solution close to the ideal, which provides maximum "group benefit" and "minimum individual regret" for the majority. As a result of the study carried out to find answers to the research questions, it was concluded that when choosing a whey protein powder, individuals took into account the product price the most and then attached importance to the amount of protein and sugar. Based on these criteria, it was concluded that it was appropriate to choose the commercially available A2 protein powder, which is produced in Turkey.

This article is structured as follows: in the second part of the study, a literature review on the subject is presented. In the third part, the processing steps of VIKOR, which is a multi-criteria decision-making method based on circular intuitionistic fuzzy sets, are discussed. In the next section, the proposed method is used for the best whey protein powder selection, and the findings will be discussed. In the last part, the conclusions, the best whey protein powder available in the market, the limitations encountered in the study, and suggestions for the future will be mentioned.

2. Literature Review

In this section, a literature review on whey protein is first represented, followed by a literature review on the fuzzy VIKOR extensions.

2.1. Whey Protein Studies

In the literature, there are studies for whey protein by different researchers and from different perspectives. On 6 March 2023, 15,118 results were found in the research conducted by selecting "all fields" in the Web of Science with the keyword "whey protein". Based on the period from 1980 to 2023, a total of 13,314 articles, 1051 review articles, 702 proceeding papers, 385 meeting abstracts, 292 book chapters, and 35 editorial materials were examined. These materials ranged from the oldest publication in 1980 to the most recent publication in 2023. Contents indexed in the Web of Science were considered as a database. Figure 1 represents the distribution of "whey protein" studies by year.

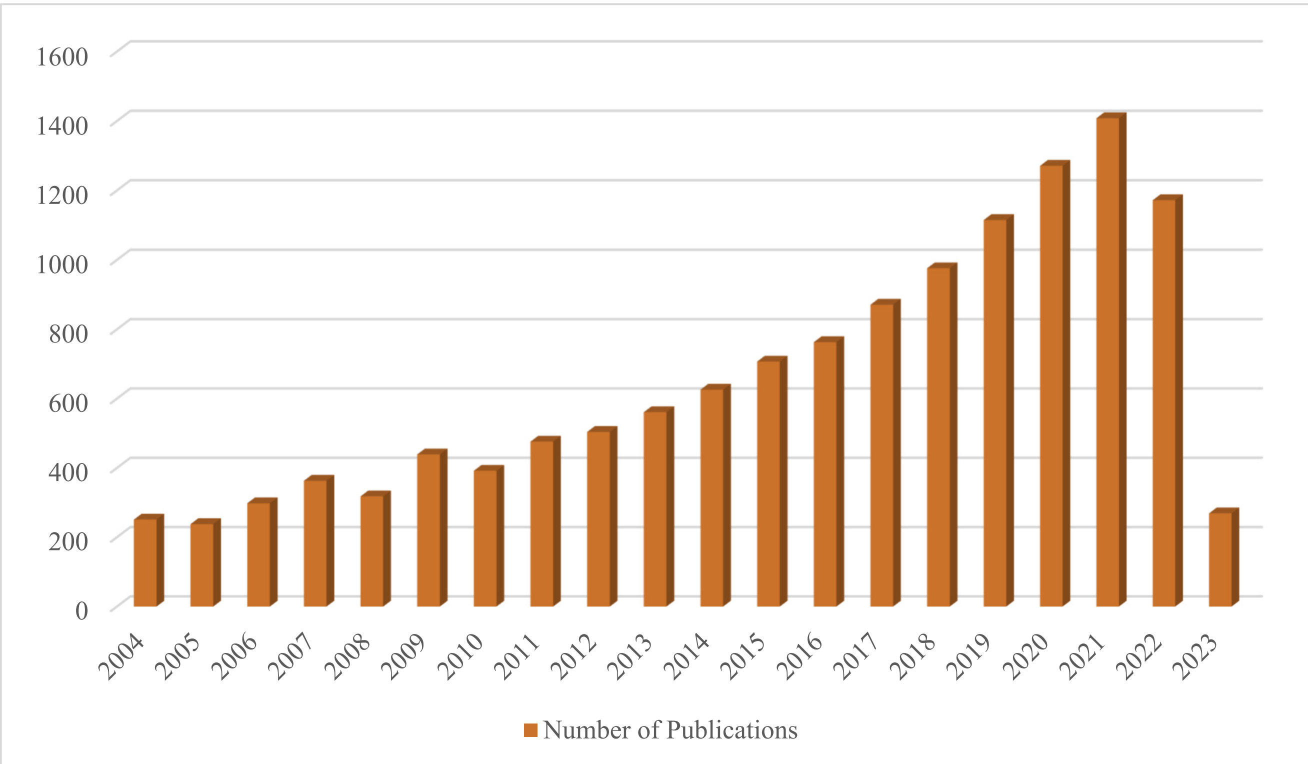

Figure 1. The distribution of "whey protein" studies by year.

In his 2013 study, Sharawy [8] aimed to investigate the effects of pre- and post-exercise whey protein supplementation on protein metabolism and muscle strength among elite wrestlers. Eighteen male wrestler volunteers participated in the study and were divided into two groups: those who received whey protein prior to and following exercise, and those who underwent certain tests. Subjects were evaluated in terms of their maximum strength in squat, chest, and arm exercises. Athletes were provided with a designated amount of whey protein supplement 40 min prior to and immediately following exercise, for three days per week over the course of twelve weeks. The results revealed significant differences in total protein, albumin, urine, creatinine, and muscle strength for athletes who consumed the supplement 40 min prior to exercise. The findings suggest that the optimal time to consume whey protein supplementation is immediately after exercise.

Since there is not enough clear information about whey proteins and their functions, Zhao et al. [9] have studied Guishan and Saanen goats in the Greek state. In this study, a quantitative analysis was performed on the determined goat cheeses. A total of five hundred proteins were determined in two different goat species. These proteins are involved in membrane structure and binding in cellular and immune system processes. With this study, the properties of the whey proteins of these two different goat cheeses were better understood.

Guefai et al. [10] analyzed twenty-five different elements in twenty different types of whey protein powder. Inductively coupled plasma mass spectrometry was used for the analysis. The potential risk associated with a daily intake of these powders has been assessed, and their bioavailability has been investigated. It was concluded that calcium, magnesium, potassium, and sodium are the predominant elements. The results obtained according to ANOVA and hierarchical cluster analysis were evaluated.

King et al. [11] conducted a study on the use of whey protein powder in normal-weight and obese individuals. The effects of whey protein powder on the body's energy balance for 48 h were investigated. The study explains the effects of protein powder on body composition and weight loss; even a small dose of whey protein powder shows that both normal-weight and obese individuals need less energy at their next meal.

A study was conducted to investigate the effect of the antioxidant property of whey protein on various tissues. Rats were used as subjects in the study and were given whey protein concentrate at a dose of one gram per kilogram for 28 days. It was observed that the redox state of the kidneys was not affected, but the antioxidant properties of the liver, small intestine, lungs, and muscles were improved. The biological benefits of whey protein were, thus, proven by the study [12].

In Pinto et al.'s study [13], 26 trace elements, both essential and non-essential/toxic, were analyzed in 49 whey protein supplements available for sale in Portugal. The results showed that iron (Fe) was the most abundant trace element, whereas cobalt (Co) was the least abundant. Daily requirements for calcium (Ca) and molybdenum (Mo) were met completely by consuming the recommended daily amount of whey protein. However, only 40% of the recommended daily intake of selenium (Se) was met. The presence of toxic elements, including lead, cadmium, mercury, and arsenic in the analyzed samples was found to be within the acceptable limits. Consequently, it can be inferred that whey proteins are considered safe products in terms of the presence of potentially harmful trace elements [13].

2.2. Fuzzy VIKOR Studies

Multi-criteria decision-making problems appear in many areas of our lives. Many methods are used by researchers to solve these problems. Basilio et al. analyzed the Web of Science and Scopus databases between 1977 and 2022 and undertook a systematic review on the subject. According to the results of this study, the most preferred methods by researchers in solving multi-criteria decision-making problems were AHP, TOPSIS, VIKOR, PROMETHEE, and ANP [14].

The first step in multi-criteria decision-making problems is to correctly determine the criteria to be used in the problem and to calculate the criteria weights correctly. Many different methods are used to determine the criterion weights. In addition to methods such as AHP, ANP, SWARA, novel methods such as CILOS, IDOCRIW, FUCOM, LBWA, SAPEVO-M, and MEREC are frequently encountered in the literature [15].

In multi-criteria decision-making problems, it is also important to determine the importance of decision-makers and their preferences on objectives. For this purpose, Chiu et al. [16] proposed a weight-induced norm (WIN) approach to group decision-making. This proposed approach adequately reflects the preferences of the decision-makers and helps to find the right result.

In the literature, there are studies for fuzzy VIKOR by different researchers and from different perspectives. On 6 March 2023, 490 results were found in the research conducted by selecting "all fields" in the Web of Science with the keyword "fuzzy VIKOR". From 2005 to 2023, a total of 424 articles, 2 review articles, and 7 book chapters were examined. These materials ranged from the oldest publication in 2005 to the most recent publication in 2023. Contents indexed in the Web of Science were considered as a database. Figure 2 represents the distribution of "fuzzy VIKOR" studies by year. Studies in the literature on the subject are summarized in the Table 1.

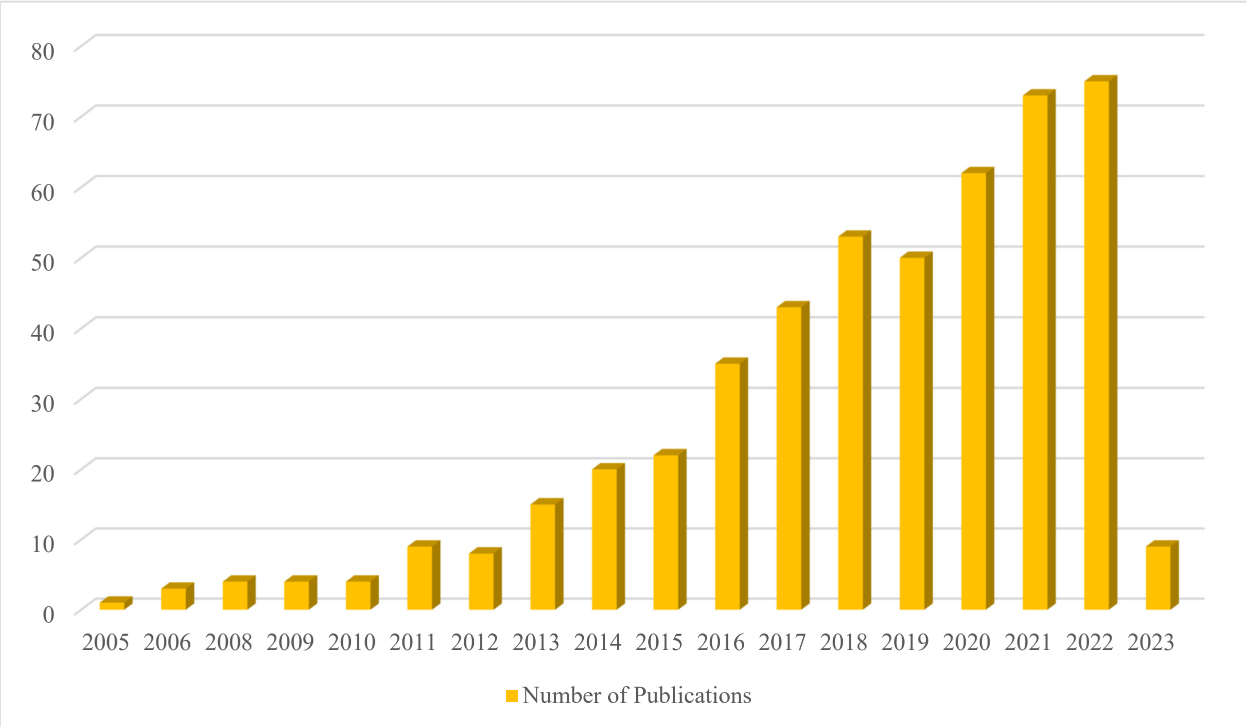

Figure 2. The distribution of "fuzzy VIKOR" studies by year.

Table 1. Summary of fuzzy VIKOR studies in the literature.

Author(s)	**Objective**
Opricovic [17]	To develop a practical application of a methodology for water resource planning by fuzzy VIKOR.
Meniz and Özkan [18]	To determine the ideal vaccine during the COVID-19 pandemic by using the VIKOR method.
Hassan et al. [19]	To identify and evaluate risks associated with the implementation of circular economy practices in the construction industry by fuzzy SWARA and VIKOR.
Ada et al. [20]	To comprehend the function of intelligent technologies and to demonstrate the ranking of different smart technologies in the acquisition and categorization of electronic waste by using fuzzy ANP and VIKOR.
Ourya and Abderafi [21]	To identify the most appropriate clean and renewable catalytic process for industrial-scale hydrogen production by using AHP and fuzzy VIKOR.
Nayeri et al. [22]	To develop a decision-making framework for researching a responsive supply chain for healthcare systems by using fuzzy VIKOR.
Yildirim and Kuzu Yıldırım [23]	To rank the satisfaction levels of municipal services by using the VIKOR method.

3. Materials and Methods

Multi-criteria decision-making problems are encountered in all areas of daily life. Many methods are used to solve these problems, such as the Analytical Hierarchy Process (AHP), VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), Analytical Network Process (ANP), and COPRAS (Complex Proportional Assessment), etc. In case of uncertainty about the environment and the information obtained, intuitionistic fuzzy sets are used. In classical set or logic theory, the belonging of an element to a set is graded sharply using the numbers 0 and 1. That is, the element is either included in that set (state 1) or not included (state 0) [24]. Fuzzy logic has found a wide application area thanks to its easy and convenient solution-finding approach to the solution of difficult and complex problems. In general, it has been the subject of many fields, such as medicine, sociology, engineering, psychology, artificial intelligence, intelligent systems, robotics, signal processing, intersection, and transportation problems. Fuzzy sets were developed by Zadeh [25], and then many researchers conducted research on fuzzy sets, and extensions of ordinary fuzzy sets were defined in the literature. The chronological order of the appearance of fuzzy sets is given in Figure 3 [26–42].

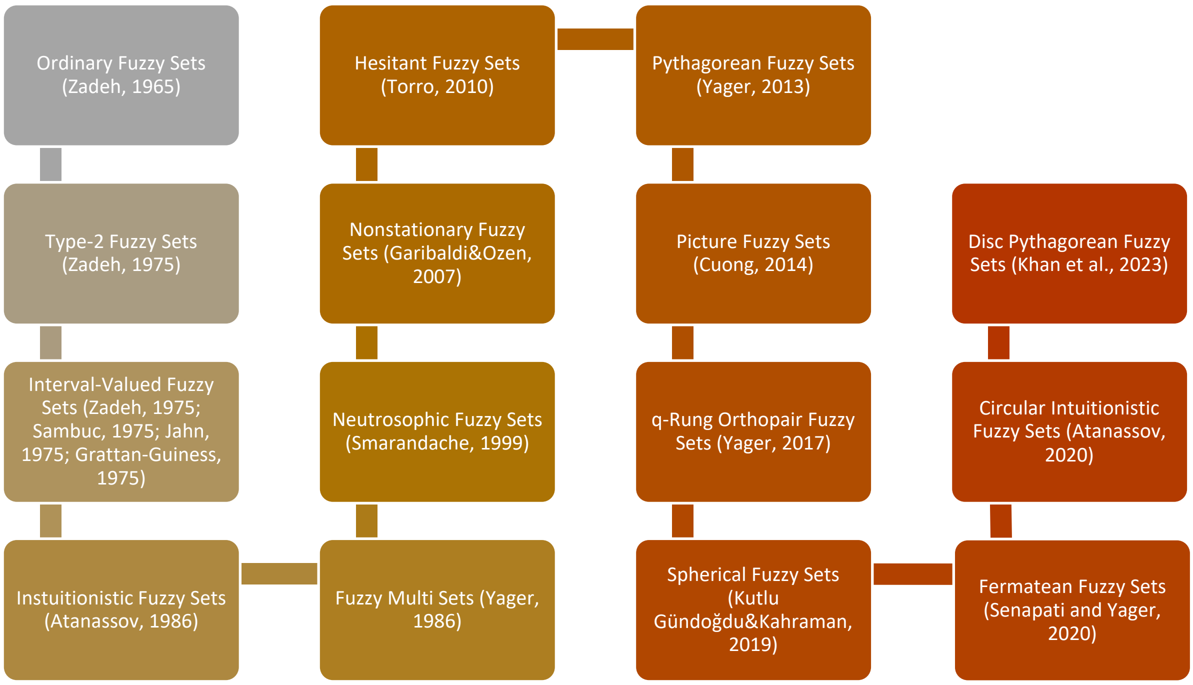

Figure 3. Chronological order of extensions of fuzzy sets [26–42].

Circular intuitionistic fuzzy sets are extensions of intuitionistic fuzzy sets. In these fuzzy sets, developed by Atanassov in 2020 [41], where the third-dimensional uncertainty of the membership function is represented by a circle, decision-makers also consider the judgments that include this uncertainty [41–45]. There are many studies in the literature on the application of fuzzy sets to many MCDM methods: fuzzy TOPSIS, fuzzy COPRAS, fuzzy VIKOR, fuzzy AHP, and fuzzy ANP, etc. This section will define general information about circular intuitionistic fuzzy sets, which form the basis of the study, and the processing steps for fuzzy VIKOR.

3.1. Preliminaries Intuitionistic and Circular Intuitionistic Fuzzy Sets

In this section, general definitions of the intuitionistic fuzzy set (IFS) and circular intuitionistic fuzzy set (C-IFS) will be given. The universal set, which is a non-void and finite set, will be symbolized by "U".

Definition 1. *For the universal set (U), the IF (I) and C-IF (I′) sets are defined as follows [41,43,44]:*

$$I = \{u,\ (m_I(u),\ ¥_I(u))\mid u \in U\}\ for\ IF \tag{1}$$

$$I' = \{u,\ (m_{I'}(u),\ ¥_{I'}(u),\ r)\mid u \in U\}\ for\ C-IFS \tag{2}$$

$$0 \le \{m_I(u) + ¥_I(u)\} \le 1 \tag{3}$$

where m_I, m is the membership degree $U \to [0,1]$, $¥_I$, $¥_{I'}$ is the non-membership degree $U \to [0,1]$, and r is the radius of the circle around $u \in U$. The degree of hesitancy (indeterminacy) of u associated with I' is calculated as below.

$$\hbar_{I'}(u) = 1 - m_{I'}(u) - ¥_{I'}(u) \tag{4}$$

For $u \in U$, a circle with radius r and centre of m(u), ¥(u) represents a circular intuitionistic fuzzy value. Generally, it is represented as $I' = (u,\ m_I(u),\ ¥_I(u); \mathrm{r})$. In order to better understand C-IFSs, it would be appropriate to make more definitions. Let $\mathcal{L} = \{(a,b)|a,b\epsilon[0,1]\&a+b \le 1)\}$. The C-IFS can be expressed as below:

$$I' = \{(u,\ \mathfrak{O}_r(m_{I'}(u),\ ¥_{I'}(u))|u \in U\} \tag{5}$$

where

$$\begin{aligned}\mathfrak{O}_r(m_{I'}(u),\ ¥_{I'}(u)) &= \left\{(a,b)|a,b \in [0,1]\&\sqrt{(m_{I'}(u)-a)^2 + (¥_{I'}(u)-b)^2} \le \mathrm{r}\right\} \cap \mathcal{L} \\ &= \left\{(a,b)|a,b \in [0,1], \sqrt{(m_{I'}(u)-a)^2 + (¥_{I'}(u)-b)^2} \le \mathrm{r}\ \&\ \mathrm{a}+\mathrm{b}\ \le\ 1\right\}\end{aligned} \tag{6}$$

Theoretically, Equation (6) creates five circle forms and is shown in Figure 4. As can be seen, the radius varies between 0 and $\sqrt{2}$; in short, $\mathrm{r} \in \left[0, \sqrt{2}\right]$. A radius of zero means that the C-IF value is equal to an ordinary IF value [43].

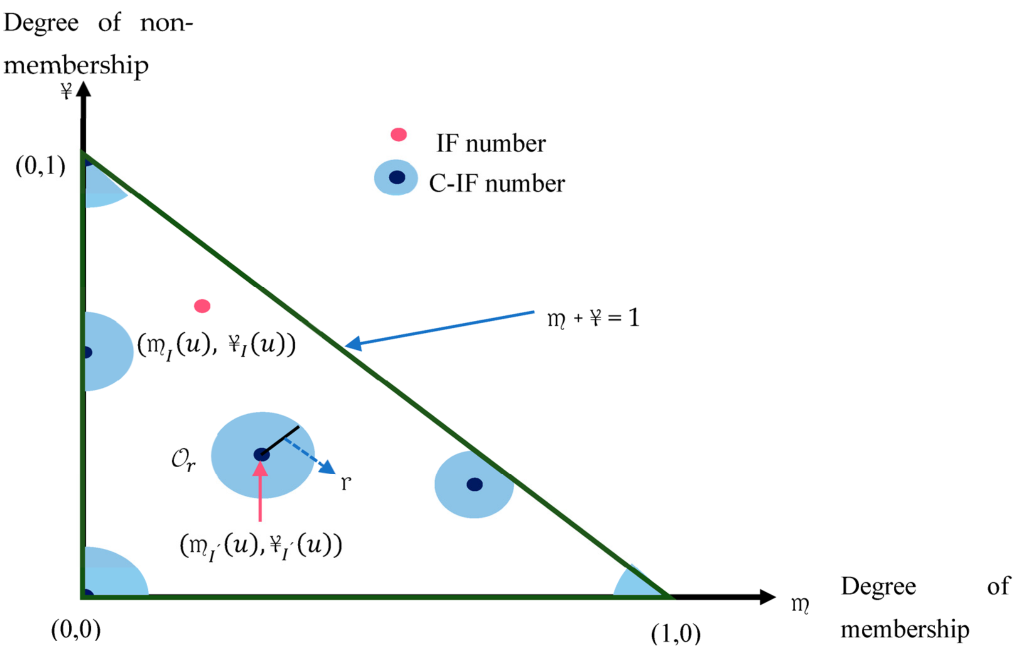

Figure 4. Geometrical interpretation of numbers of an IF and a C-IF [43].

Definition 2. *An $IFS - C_i$ and each of them contains k_i is defined as the intuitionistic fuzzy pairs which have form of $[(\mathfrak{m}_{i,1},\ \text{¥}_{i,1}),\ (\mathfrak{m}_{i,2},\ \text{¥}_{i,2}),\ldots]$ where i is the number of $IFS - C_i$ and each of them contains k_i IF pairs. C-IFS is formed by taking the arithmetic average of the IF pairs as follows [44,45].*

$$[\mathfrak{m}(C_i),\ \text{¥}(C_i)] = \left[\frac{\sum_{j=1}^{k_i}\mathfrak{m}_{i,j}}{k_i},\ \frac{\sum_{j=1}^{k_i}\text{¥}_{i,j}}{k_i}\right] \tag{7}$$

where k_i is the number of IF pairs in C_i.

After that, the maximum Euclidean distance is obtained using the following equation, which gives the radius of the $\mathfrak{m}(C_i),\ \text{¥}(C_i)$.

$$\mathrm{r}_i = \max_{1\le j\le k_i}\sqrt{(\mathfrak{m}(C_i) - \mathfrak{m}_{i,j})^2 + (\text{¥}(C_i) - \text{¥}_{i,j})^2} \tag{8}$$

Definition 3. *Let us define two different C-IFSs and their basic operations of them listed below. The operations are based on minimum and maximum radius separately. Because thanks to these values, it is ensured that the results are obtained with minimum and maximum uncertainty levels. That is, a smaller radius indicates less uncertainty, while a larger radius indicates more uncertainty [41,44,45].*

For $C_1 = \langle \mathfrak{m}_{C_1}(u), \text{¥}_{C_1}(u); r_1\rangle$ and $C_2 = \langle \mathfrak{m}_{C_2}(u), \text{¥}_{C_2}(u); r_2\rangle$

$$C_1 \cap_{min} C_2 = \{\langle u, min(\mathfrak{m}_{C_1}(u), \mathfrak{m}_{C_2}(u)), max(\text{¥}_{C_1}(u), \text{¥}_{C_2}(u)); min(r_1, r_2)\rangle \,|u \in U\} \tag{9}$$

$$C_1 \cap_{max} C_2 = \{\langle u, min(\mathfrak{m}_{C_1}(u), \mathfrak{m}_{C_2}(u)), max(\text{¥}_{C_1}(u), \text{¥}_{C_2}(u)); max(r_1, r_2)\rangle \,|u \in U\} \tag{10}$$

$$C_1 \cup_{min} C_2 = \{\langle u, max(\mathfrak{m}_{C_1}(u), \mathfrak{m}_{C_2}(u)), min(\text{¥}_{C_1}(u), \text{¥}_{C_2}(u)); min(r_1, r_2)\rangle \,|u \in U\} \tag{11}$$

$$C_1 \cup_{max} C_2 = \{\langle u, max(\mathfrak{m}_{C_1}(u), \mathfrak{m}_{C_2}(u)), min(\text{¥}_{C_1}(u), \text{¥}_{C_2}(u)); max(r_1, r_2)\rangle \,|u \in U\} \tag{12}$$

$$C_1 \oplus_{min} C_2 = \{\langle u, \mathfrak{m}_{C_1}(u) + \mathfrak{m}_{C_2}(u) - \mathfrak{m}_{C_1}(u) * \mathfrak{m}_{C_2}(u),\ \text{¥}_{C_1}(u) * \text{¥}_{C_2}(u); min(r_1, r_2)\rangle \,|u \in U\} \tag{13}$$

$$C_1 \oplus_{max} C_2 = \{\langle u, \mathfrak{m}_{C_1}(u) + \mathfrak{m}_{C_2}(u) - \mathfrak{m}_{C_1}(u) * \mathfrak{m}_{C_2}(u),\ \text{¥}_{C_1}(u) * \text{¥}_{C_2}(u); max(r_1, r_2)\rangle \,|u \in U\} \tag{14}$$

$$C_1 \otimes_{min} C_2 = \{\langle u, \mathfrak{m}_{C_1}(u) * \mathfrak{m}_{C_2}(u),\ \text{¥}_{C_1}(u) + \text{¥}_{C_2}(u) - \text{¥}_{C_1}(u) * \text{¥}_{C_2}(u); min(r_1, r_2)\rangle \,|u \in U\} \tag{15}$$

$$C_1 \otimes_{max} C_2 = \{\langle u, \mathfrak{m}_{C_1}(u) * \mathfrak{m}_{C_2}(u),\ \text{¥}_{C_1}(u) + \text{¥}_{C_2}(u) - \text{¥}_{C_1}(u) * \text{¥}_{C_2}(u); max(r_1, r_2)\rangle \,|u \in U\} \tag{16}$$

3.2. VIKOR Based on Circular Intuitionistic Fuzzy Sets

In this section, the processing steps of the C-IF VIKOR method proposed by Chen [44] will be introduced.

Step 1. Initial decision matrices are constructed by using linguistic values (Table 2). Experts evaluate all alternatives due to determined criteria. E_k represents the set of experts $(k = 1, 2, \ldots, l)$. The obtained linguistic decision values are converted to IF matrices.

$$M^k = \langle X_{ij}^k \rangle = \langle (\text{ɱ}_{ij}^k, \text{¥}_{ij}^k) \rangle \; k = 1, 2, \ldots, l \tag{17}$$

Table 2. Linguistic values to evaluate the alternatives due to the criteria.

Linguistic Terms	**Intuitionistic Fuzzy Numbers**	
	ɱ	**¥**
Extremely High Value (EHV)	0.90	0.10
Very High Value (VHV)	0.80	0.15
High Value (HV)	0.70	0.25
Above Average Value (AAV)	0.60	0.35
Average Value (AV)	0.50	0.45
Below Average Value (BAV)	0.40	0.55
Low Value (LV)	0.30	0.65
Very Low Value (VLV)	0.20	0.75
Extremely Low Value (ELV)	0.10	0.90

Step 2. The following equation is used to reduce the intuitionistic fuzzy matrices obtained as a result of the evaluations made by the experts into a single matrix.

$$\langle \text{ɱ}_{ij}, \text{¥}_{ij} \rangle = \left\langle \frac{\sum_{k=1}^{l} w_k * \text{ɱ}_{ij}^k}{l}, \frac{\sum_{k=1}^{l} w_k * \text{¥}_{ij}^k}{l} \right\rangle. \tag{18}$$

Here w_k denotes the weight of each of the experts $(W = w_1,\ w_2, \ldots, w_k)$. The radius is calculated for each IF value:

$$r_{ij} = \max_{k=1,2,\ldots,l} \sqrt{\left(\text{ɱ}_{ij} - \text{ɱ}_{ij}^k \right)^2 + \left(\text{¥}_{ij} - \text{¥}_{ij}^k \right)^2}. \tag{19}$$

Step 3. After the radius calculations, a circular intuitionistic fuzzy set matrix is created.

$$M = \langle X_{ij} \rangle = \langle (\text{ɱ}_{ij},\ \text{¥}_{ij};\ r_{ij}) \rangle \; i = 1, 2, \ldots, m; j = 1, 2, \ldots, n. \tag{20}$$

Step 4. It is necessary to determine the criteria weights, which is an important step in the solution of multi-criteria decision-making problems. The fact that the criteria weights are always the same does not mean that real-life problems are reflected correctly. Each criterion has a weight in the range of 0 to 1, and the sum of the weights of the criteria must be equal to 1. Experts evaluate all criteria by using linguistic terms (Table 3). The weight vector is calculated by using the chi-square distance-based divergence measure, as below.

Let $P_1 = \left\{ \left(u_i,\ \text{ɱ}_{P_1}(u_i), \text{¥}_{P_1}(u_i); r_{P_1}(u_i) \right) \middle| \ i = 1, 2, \ldots, n \right\}$ and $P_2 = \left\{ \left(u_i,\ \text{ɱ}_{P_2}(u_i), \text{¥}_{P_2}(u_i); r_{P_2}(u_i) \right) \middle| \ i = 1, 2, \ldots, n \right\}$

$$\overline{D}(P_1, P_2) = \frac{1}{n} \sum_{i=1}^{n} \left[\frac{\left(\text{ɱ}_{P_1}(u_i) - \text{ɱ}_{P_2}(u_i) \right)^2}{1 + \text{ɱ}_{P_1}(u_i) + \text{ɱ}_{P_2}(u_i)} + \frac{\left(\text{¥}_{P_1}(u_i) - \text{¥}_{P_2}(u_i) \right)^2}{1 + \text{¥}_{P_1}(u_i) + \text{¥}_{P_2}(u_i)} + \frac{\left(r_{P_1}(u_i) - r_{P_2}(u_i) \right)^2}{1 + r_{P_1}(u_i) + r_{P_2}(u_i)} \right] \tag{21}$$

$$w_j = \frac{\frac{1}{m-1} \left(\sum_{i=1}^{m} \sum_{k=1}^{m} \overline{D}_k \left(X_{ij}, X_{kj} \right) \right)}{\sum_{j=1}^{n} \left[\frac{1}{m-1} \left(\sum_{i=1}^{m} \sum_{k=1}^{m} \overline{D}_k \left(X_{ij}, X_{kj} \right) \right) \right]} \; j = 1, 2, \ldots, n. \tag{22}$$

Table 3. Linguistic values to evaluate the criteria.

Linguistic Terms	Intuitionistic Fuzzy Numbers	
	$\mathfrak{m}$	¥
Extremely High Importance (EHI)	0.90	0.10
Very High Importance (VHI)	0.80	0.15
High Importance (HI)	0.70	0.25
Above Average Importance (AAI)	0.60	0.35
Average Importance (AI)	0.50	0.45
Below Average Importance (BAI)	0.40	0.55
Low Importance (LI)	0.30	0.65
Very Low Importance (VLI)	0.20	0.75
Extremely Low Importance (ELI)	0.10	0.90

Step 5. For each criterion, there are positive ideal (PI) and negative ideal (NI) C-IFVs. These values help to reach the best alternative and move away from the worst alternative. These values are calculated using the following equations:

$$PI_j = \left\{ \left(\max_{i=1,\ldots,m} \left(\mathfrak{m}_{ij} \right), \min_{i=1,\ldots,m} \left(¥_{ij} \right); \max_{i=1,\ldots,m} \left(r_{ij} \right) \right) \right\} \tag{23}$$

$$NI_j = \left\{ \left(\min_{i=1,\ldots,m} \left(\mathfrak{m}_{ij} \right), \max_{i=1,\ldots,m} \left(¥_{ij} \right); \min_{i=1,\ldots,m} \left(r_{ij} \right) \right) \right\} \tag{24}$$

Step 6. The divergence measure given above is used to calculate the divergence between each C-IFVs, PI–C-IFVs, and PI–NI C-IFVs.

Step 7. For each alternative, the group utility index $\left(\overline{S}\right)$, individual regret index $\left(\overline{R}\right)$, and compromise index $\left(\overline{Q}\right)$ are calculated by using the following equations:

$$\overline{S}(u_i) = \sum_{j=1}^{n} w_j * \frac{\overline{D}_k\left(PI_j, X_{ij}\right)}{\overline{D}_k\left(PI_j, NI_j\right)} \tag{25}$$

$$\overline{R}(u_i) = \max_{j=1,\ldots,n} w_j * \frac{\overline{D}_k\left(PI_j, X_{ij}\right)}{\overline{D}_k\left(PI_j, NI_j\right)} \tag{26}$$

$$\overline{Q}(u_i) = \frac{v * \overline{S}(u_i) - \min_{i'=1,\ldots,m} \overline{S}(u_{i'})}{\max_{i'=1,\ldots,m} \overline{S}(u_{i'}) - \min_{i'=1,\ldots,m} \overline{S}(u_{i'})} + \frac{(1-v) * \overline{R}(u_i) - \min_{i'=1,\ldots,m} \overline{R}(u_{i'})}{\max_{i'=1,\ldots,m} \overline{R}(u_{i'}) - \min_{i'=1,\ldots,m} \overline{R}(u_{i'})} \tag{27}$$

where X_{ij} is the C-IFV for i^{th} alternative against j^{th} criterion and v is the weight that provides maximum group utility.

Step 8. The $\overline{S}$, $\overline{R}$, and $\overline{Q}$ values are sorted in ascending order. If two conditions below are satisfied, it considers the first option as the compromise solution, which provides the best rank in ordering the alternatives due to $\overline{Q}$ values from smallest to largest.

Condition 1. *Acceptable advantage:*

$$X'' - X' \geq \frac{1}{m-1} \tag{28}$$

where X' is the first minimum, X'' is the second minimum value in the $\overline{Q}$ list, and m is the number of alternatives.

Condition 2. *Acceptable stability: According to the $\overline{S}$ and $\overline{R}$ values, X' should be the best alternative.*

If one of the conditions given above cannot be met, the set of compromise solutions is suggested as follows:

- if Condition 1 is not met a compromise solution set consists of T members, where T is the maximum for which

$$X^T - X' < \frac{1}{m-1} \tag{29}$$

- if Condition 2 is not met, the first and second alternatives are determined as the best compromise solution.

4. Application: Whey Protein Supplement Selection

MCDM methods are commonly employed in various sectors to address a range of problems. In this section, different commercially available whey proteins have been assessed and ranked according to a set of criteria. Moreover, it has provided a roadmap outlining the criteria that should be prioritized by consumers, sports center managers, or coaches in the decision-making process. The flow chart of the problem is shown in Figure 5.

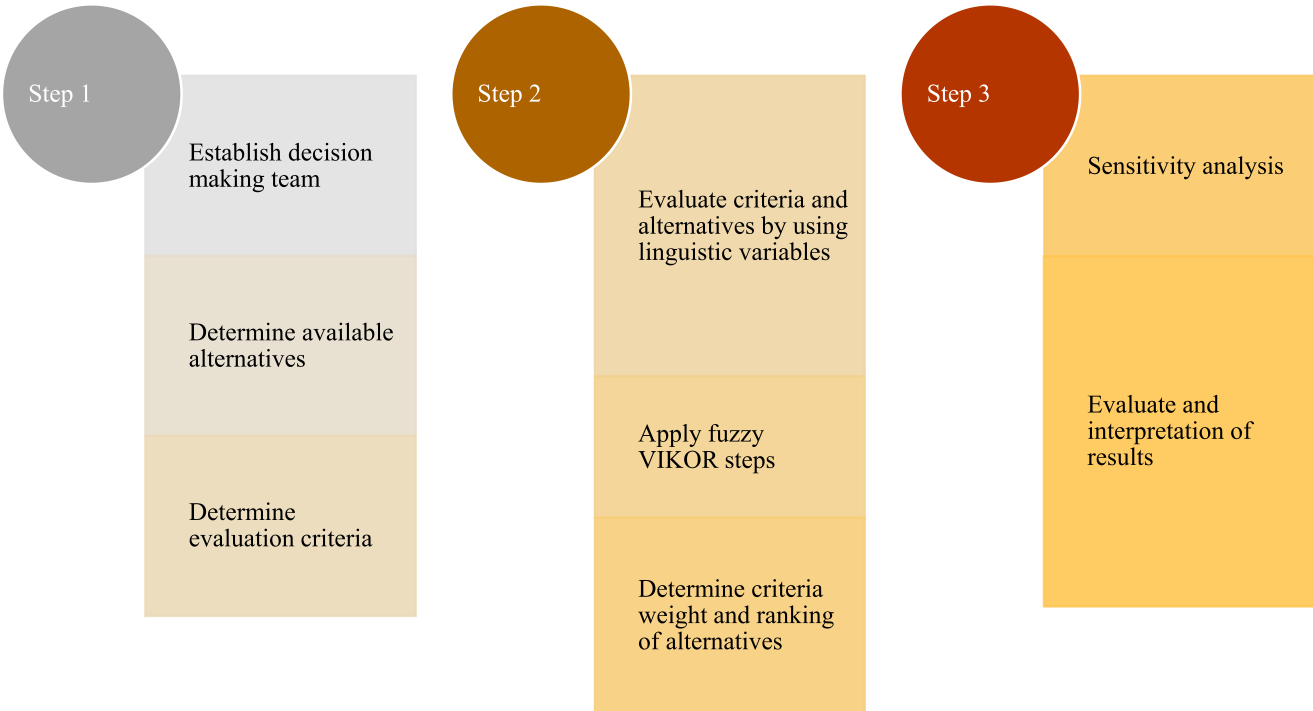

Figure 5. Flow chart of the problem.

4.1. Determine Criteria and Alternatives

The initial stage of the problem involved the formation of a decision-making team comprising professional athletes, the sports center manager, officials from a protein powder-producing company, and individuals who engage in regular sports activities. In accordance with expert consensus, alternative options for whey protein powder and corresponding evaluation criteria were established. Detailed information on the identified criteria and alternatives can be found in Tables 4 and 5. Subsequently, each decision-maker assessed the established criteria utilizing Table 3 and evaluated the alternative options using Table 2. While the scores of each alternative according to each criterion except taste and mixing performance were obtained from the official websites of the products, the values of the taste and mixing performance were formed by taking the evaluation scores of the users from the shopping sites where the products are officially sold.

Table 4. Criteria and their definitions.

Code	Name	Definition
C1	Product Price ($)	It is the price of one gram of product.
C2	Protein (%)	It expresses the amount of protein in the product.
C3	Calories (cal)	It is the calorie value of 30 g product.
C4	Carbohydrate (%)	It expresses the amount of carbohydrates in the product.
C5	Fat (%)	It expresses the amount of fat in the product.
C6	Sugar (%)	It expresses the amount of sugar in the product.
C7	Number of servings	It is the number that shows the maximum number of servings in a box. A serving amount can usually be 25 g or 30 g.
C8	Taste	It expresses the taste and pleasure taken by the users of the product.
C9	Mixing Performance	It expresses the mixing performance of the powdered product in the liquid (homogeneity).

Table 5. Alternatives and their definitions.

Code	Explanation
A1	Product A is the product of a sports company founded in 1936, headquartered in the United States, and operating in the fitness industry.
A2	Product B is manufactured by a Turkish company with a strong position in the fitness industry.
A3	Product C is offered for sale on the market by a company originating in Hungary.
A4	Product D is the product of a company that is a worldwide brand of sports nutrition and was founded in the United States in 1986.
A5	Product E has been produced as a sports supplement by the company established in the United Kingdom in 1996.
A6	Product F has been produced as a sports nutrition and sports supplement by a German company, which was established in 1977.
A7	Product G is produced by a Polish company founded in 1990 as a sports nutrition and sports supplement.

The team of decision-makers evaluated the criteria and alternatives, and the results of their evaluation can be found in Tables 6 and 7.

Table 6. Linguistic evaluations of criteria for each decision maker (DM).

	DM1	DM2	DM3	DM4	DM5
C1	EHI	HI	ELI	AAI	AAI
C2	EHI	EHI	EHI	VHI	VHI
C3	HI	VLI	HI	HI	BAI
C4	AAI	BAI	HI	HI	AI
C5	AAI	LI	AAI	VHI	LI
C6	HI	LI	AAI	EHI	LI
C7	AI	VLI	LI	HI	BAI
C8	LI	VHI	AI	AI	VLI
C9	AI	LI	ELI	HI	BAI

Table 7. Linguistic decision matrix for each decision maker (DM).

DMs	Alternatives	Criteria								
		C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
DM1	A1	ELV	VHV	AAV	HV	AAV	AV	HV	VHV	EHV
	A2	EHV	EHV	EHV	EHV	AV	HV	HV	BAV	AV
	A3	EHV	HV	BAV	EHV	BAV	AV	VHV	EHV	VHV
	A4	LV	VHV	AV	VHV	VHV	AAV	AAV	AV	LV
	A5	VLV	EHV	VHV	HV	EHV	HV	VLV	AAV	VHV
	A6	AV	HV	AAV	BAV	HV	ELV	BAV	HV	EHV
	A7	HV	AAV	EHV	VLV	AAV	VLV	LV	VLV	VHV
DM2	A1	VLV	AAV	AV	AAV	AAV	AAV	HV	EHV	EHV
	A2	VHV	HV	AAV	VHV	VLV	HV	HV	HV	AAV
	A3	HV	AV	LV	VHV	VLV	AAV	HV	EHV	HV
	A4	LV	AAV	BAV	HV	HV	HV	AV	HV	AV
	A5	VLV	HV	AAV	AAV	VHV	VHV	LV	VHV	HV
	A6	BAV	AV	AV	VLV	HV	VLV	AV	VHV	VHV
	A7	AV	BAV	HV	ELV	AAV	LV	BAV	LV	HV
DM3	A1	ELV	AAV	AV	AV	AV	AV	HV	VHV	VHV
	A2	EHV	VHV	HV	HV	LV	HV	HV	AAV	HV
	A3	AAV	BAV	BAV	HV	ELV	AV	VHV	VHV	VHV
	A4	VLV	HV	AV	AAV	VHV	AAV	AAV	AAV	AV
	A5	ELV	VHV	HV	AAV	EHV	HV	VLV	HV	VHV
	A6	VLV	BAV	AV	BAV	HV	VLV	BAV	HV	VHV
	A7	BAV	LV	VHV	ELV	AV	LV	LV	AV	VHV
DM4	A1	ELV	AV	AV	HV	BAV	AAV	VHV	HV	EHV
	A2	EHV	HV	AAV	VHV	LV	AAV	HV	AV	AAV
	A3	HV	BAV	BAV	VHV	VLV	AAV	EHV	HV	HV
	A4	LV	AV	AV	HV	AAV	HV	AAV	AV	AV
	A5	VLV	HV	HV	HV	VHV	VHV	ELV	AAV	HV
	A6	BAV	BAV	AV	VLV	AV	VLV	LV	AAV	VHV
	A7	AV	LV	VHV	ELV	BAV	LV	VLV	BAV	HV
DM5	A1	VLV	HV	BAV	AV	BAV	AV	HV	VHV	VHV
	A2	VHV	VHV	AV	VHV	LV	AV	HV	AAV	AAV
	A3	HV	AAV	LV	VHV	VLV	AV	VHV	VHV	HV
	A4	VLV	HV	LV	AAV	AAV	AAV	AV	AAV	LV
	A5	VLV	VHV	AAV	AAV	VHV	HV	LV	HV	HV
	A6	AAV	AAV	BAV	VLV	AV	VLV	AV	HV	HV
	A7	AAV	AV	HV	ELV	BAV	LV	BAV	VLV	HV

4.2. Aggregate Decision Matrices and Criteria Weights

By using Equation (18), the evaluations made by five decision-makers were reduced to a single matrix. Radius values for these combined fuzzy numbers were obtained by using Equation (19). The results of the criteria and alternatives are as in Tables 8 and 9.

Each of the five decision-makers' knowledge and experience on the subject at hand were deemed equal.

$$(ɱ_{11}; ¥_{11}) = \left[\frac{0.2*(0.9+0.7+0.1+0.6+0.6)}{5}; \frac{0.2*(0.1+0.25+0.9+0.35+0.35)}{5}\right] = (0.116; 0.078)$$

$$\mathrm{r}_{11} = \max\left(\begin{array}{c}\sqrt{(0.116-0.9)^2+(0.078-0.1)^2}; \sqrt{(0.116-0.7)^2+(0.078-0.25)^2}; \\ \sqrt{(0.116-0.1)^2+(0.078-0.9)^2}; \sqrt{(0.116-0.6)^2+(0.078-0.35)^2}; \\ \sqrt{(0.116-0.6)^2+(0.078-0.35)^2}\end{array}\right)$$

Table 8. Aggregated circular intuitionistic fuzzy criteria weight matrix.

Criteria	ɱ	¥	Maximum Radius (r)
C1	0.116	0.078	0.822
C2	0.164	0.030	0.739
C3	0.108	0.082	0.674
C4	0.116	0.074	0.610
C5	0.104	0.086	0.699
C6	0.112	0.080	0.788
C7	0.084	0.106	0.654
C8	0.092	0.098	0.710
C9	0.080	0.112	0.788

Table 9. Circular intuitionistic fuzzy decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	(0.028, 0.168; 0.736)	(0.168, 0.128; 0.678)	(0.128, 0.062; 0.564)	(0.062, 0.100; 0.607)	(0.100, 0.090; 0.564)	(0.090, 0.120; 0.560)	(0.120, 0.070; 0.664)	(0.070, 0.100; 0.743)	(0.100, 0.090; 0.732)
A2	(0.172, 0.024; 0.732)	(0.024, 0.156; 0.747)	(0.156, 0.036; 0.769)	(0.036, 0.132; 0.743)	(0.132, 0.060; 0.639)	(0.060, 0.160; 0.602)	(0.160, 0.032; 0.595)	(0.032, 0.064; 0.613)	(0.064, 0.126; 0.607)
A3	(0.144, 0.048; 0.758)	(0.048, 0.104; 0.618)	(0.104, 0.086; 0.579)	(0.086, 0.072; 0.743)	(0.072, 0.118; 0.754)	(0.118, 0.160; 0.560)	(0.160, 0.032; 0.743)	(0.032, 0.044; 0.739)	(0.044, 0.148; 0.661)
A4	(0.052, 0.138; 0.630)	(0.138, 0.132; 0.674)	(0.132, 0.058; 0.588)	(0.058, 0.088; 0.671)	(0.088, 0.102; 0.668)	(0.102, 0.136; 0.602)	(0.136, 0.054; 0.559)	(0.054, 0.140; 0.610)	(0.140, 0.050; 0.585)
A5	(0.036, 0.156; 0.747)	(0.156, 0.156; 0.747)	(0.156, 0.036; 0.671)	(0.036, 0.136; 0.602)	(0.136, 0.054; 0.736)	(0.054, 0.128; 0.661)	(0.128, 0.062; 0.754)	(0.062, 0.168; 0.671)	(0.168, 0.026; 0.661)
A6	(0.084, 0.106; 0.654)	(0.106, 0.104; 0.618)	(0.104, 0.086; 0.564)	(0.086, 0.100; 0.633)	(0.100, 0.090; 0.605)	(0.090, 0.056; 0.747)	(0.056, 0.134; 0.585)	(0.134, 0.124; 0.668)	(0.124, 0.066; 0.743)
A7	(0.108, 0.082; 0.615)	(0.082, 0.084; 0.585)	(0.084, 0.106; 0.747)	(0.106, 0.156; 0.730)	(0.156, 0.036; 0.564)	(0.036, 0.024; 0.633)	(0.024, 0.174; 0.639)	(0.174, 0.100; 0.639)	(0.100, 0.090; 0.661)

For alternatives, calculations are as follows:

$$\mathbf{x_{11}} = \left[\frac{0.2*(0.1+0.2+0.1+0.1+0.2)}{5}; \frac{0.2*(0.9+0.75+0.9+0.9+0.75)}{5}\right] = (0.028; 0.168)$$

$$\mathrm{r}_{11} = \max\begin{pmatrix} \sqrt{(0.028-0.1)^2+(0.168-0.9)^2}; \sqrt{(0.028-0.2)^2+(0.168-0.75)^2}; \\ \sqrt{(0.028-0.1)^2+(0.168-0.9)^2}; \sqrt{(0.028-0.1)^2+(0.168-0.9)^2}; \\ \sqrt{(0.028-0.2)^2+(0.168-0.75)^2} \end{pmatrix} = 0.736$$

The divergence measure was computed utilizing Equation (21), while the weights of the criteria were determined by utilizing Equation (22):

$$w_1 = \frac{\dfrac{\left[\frac{(0.116-0.9)^2}{1+0.116+0.9} + \frac{(0.078-0.1)^2}{1+0.078+0.1} + \frac{(0.822-0.784)^2}{1+0.822+0.784}\right] + \ldots + \left[\frac{(0.116-0.6)^2}{1+0.116+0.6} + \frac{(0.078-0.35)^2}{1+0.078+0.35} + \frac{(0.822-0.555)^2}{1+0.822+0.555}\right]}{5}}{(0.262 + 0.243 + \ldots + 0.237)}$$

Upon examination of Figure 6, it becomes apparent that the product price criterion carries the most weight, followed by protein amount, sugar amount, mixing performance, and taste criteria. Conversely, the carbohydrate amount criterion carries the least amount of weight (C1 > C2 > C6 > C9 > C8 > C3 > C5 > C7 > C4). During the current global crisis period, consumers have begun to prioritize product price when making purchasing decisions.

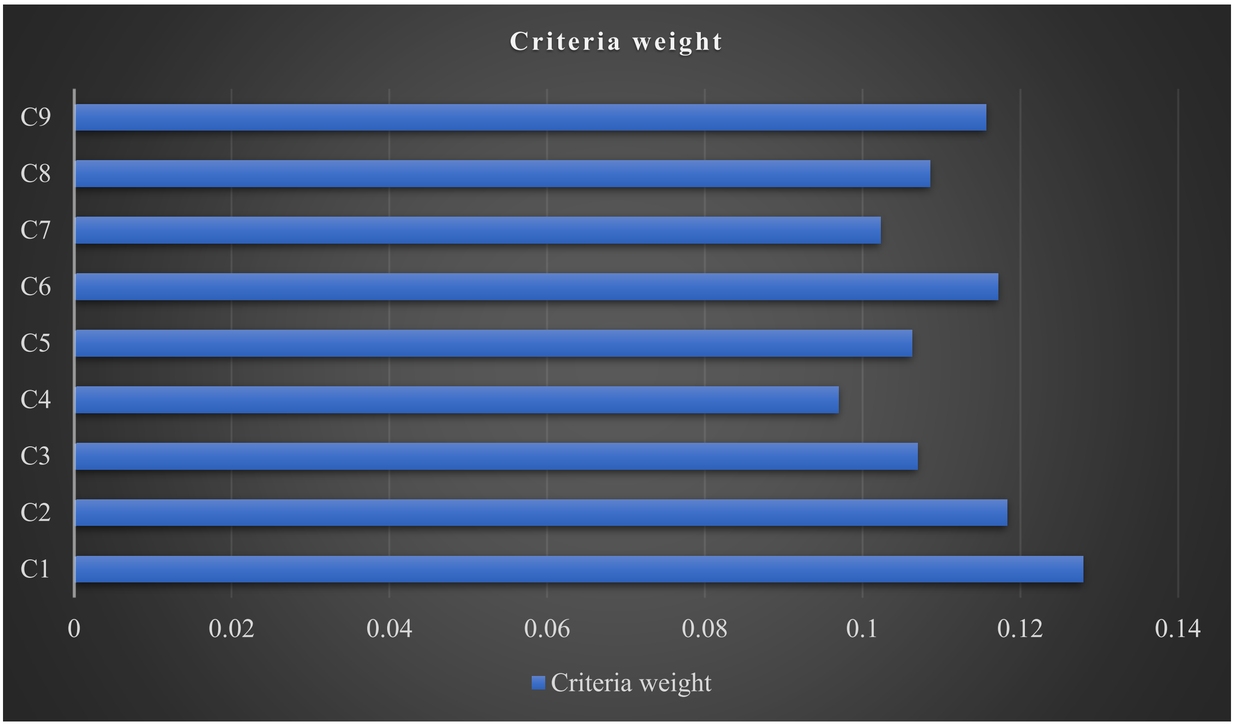

Figure 6. Weight of criteria.

4.3. Evaluation of Alternatives

To evaluate commercially available whey proteins from various companies and countries, positive ideal and negative ideal circular intuitionistic fuzzy values were computed using Equations (25) and (26). These values were utilized to identify the most favorable and least favorable alternatives for each criterion (Table 10). Divergence measures were calculated by using Equation (21), and results are given in Table 11.

$$PI_1 = \begin{bmatrix} \max(0.028, 0.172, 0.144, \ldots, 0.108), min(0.168, 0.024, 0.048, \ldots, 0.082); \\ max(0.736, 0.732, 0.758, \ldots, 0.615) \end{bmatrix}$$
$$= (0.172, 0.024; 0.758)$$

$$NI_1 = \begin{bmatrix} \min(0.028, 0.172, 0.144, \ldots, 0.108), max(0.168, 0.024, 0.048, \ldots, 0.082); \\ min(0.736, 0.732, 0.758, \ldots, 0.615) \end{bmatrix}$$
$$= (0.028, 0.168; 0.615)$$

$$D_{11} = \left[\frac{(0.028 - 0.172)^2}{1 + 0.028 + 0.172} + \frac{(0.168 - 0.024)^2}{1 + 0.168 + 0.024} + \frac{(0.736 - 0.758)^2}{1 + 0.736 + 0.758} \right] = 0.03487$$

Table 10. Positive ideal (PI) and negative ideal (NI) C-IFVs.

Criteria Code	PI_j	NI_j
C1	(0.172, 0.024; 0.758)	(0.028, 0.168; 0.615)
C2	(0.156, 0.036; 0.747)	(0.084, 0.106; 0.585)
C3	(0.156, 0.036; 0.769)	(0.072, 0.118; 0.564)
C4	(0.160, 0.032; 0.743)	(0.024, 0.174; 0.602)
C5	(0.168, 0.026; 0.754)	(0.044, 0.148; 0.564)
C6	(0.148, 0.042; 0.747)	(0.036, 0.156; 0.560)
C7	(0.160, 0.032; 0.754)	(0.044, 0.148; 0.559)
C8	(0.164, 0.030; 0.743)	(0.064, 0.126; 0.610)
C9	(0.172, 0.024; 0.743)	(0.084, 0.106; 0.585)

Table 11. Divergence measures from C-IFVs-PIj and PIj-NIj.

$D = CIFVs, PI_j$	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.03487	0.00545	0.02424	0.01360	0.02424	0.02307	0.00466	0.00026	0.00027
A2	0.00042	0.00000	0.00117	0.00003	0.01881	0.01013	0.01026	0.01073	0.01032
A3	0.00029	0.01391	0.02699	0.00029	0.02114	0.02243	0.00029	0.00043	0.00490
A4	0.02465	0.00319	0.01886	0.00305	0.00298	0.01010	0.01850	0.01065	0.02015
A5	0.02879	0.00022	0.00436	0.01223	0.00014	0.00414	0.02536	0.00436	0.00414
A6	0.01045	0.01026	0.01841	0.01970	0.00956	0.02144	0.01807	0.00271	0.00021
A7	0.01250	0.02136	0.00005	0.03258	0.02152	0.02400	0.02073	0.02073	0.00380
$D = PI_j, NI_j$	0.04322	0.01965	0.02967	0.04082	0.04103	0.03652	0.03909	0.02365	0.02281

$\overline{S}$, $\overline{R}$, *and* $\overline{Q}$ values were calculated using Equations (25)–(27), respectively. According to the obtained $\overline{S}$, $\overline{R}$, *and* $\overline{Q}$ values, the alternatives are ordered from smallest to largest. Alternative A2, which was in first place, providing acceptable advantage and stability conditions, was found to be the most suitable whey protein according to the determined criteria. The summary results and ranking of alternatives are shown in Table 12.

$$\overline{S} = \left(0.128 * \frac{0.03487}{0.04322}\right) + \left(0.118 * \frac{0.00545}{0.01965}\right) + \ldots + \left(0.116 * \frac{0.00027}{0.02281}\right) = 0.407$$

$$\overline{R} = \max(0.1033,\ 0.0328,\ \ldots,\ 0.00136) = 0.1033$$

For $v = 0.5$;

$$\overline{Q} = 0.5 * \frac{0.407 - 0.215}{0.546 - 0.215} + (1 - 0.5) * \frac{0.103 - 0.052}{0.130 - 0.052} = 0.617$$

Table 12. $\overline{S}$, $\overline{R}$, *and* $\overline{Q}$ values for $v = 0.5$ and ranking of alternatives.

v = 0.5	A1	A2	A3	A4	A5	A6	A7	Ranking
$\overline{S}$	0.407	0.215	0.337	0.407	0.252	0.360	0.546	A2 > A5 > A3 > A6 > A4 > A1 > A7
$\overline{R}$	0.103	0.052	0.097	0.102	0.085	0.069	0.130	A2 > A6 > A5 > A3 > A4 > A1 > A7
$\overline{Q}$	0.617	0.000	0.472	0.609	0.267	0.325	1.000	A2 > A5 > A6 > A3 > A4 > A1 > A7

4.4. Sensitivity Analysis

In this section, a sensitivity analysis will be conducted to investigate how the ranking of alternatives changes under various conditions in the solution of the research problem. Initially, the maximum values of group utility, which are utilized to calculate the compromise index value, were modified, and the resulting changes in the rankings of the alternatives were observed. The outcomes were evaluated by incrementally increasing the maximum group utility values by one-tenth within the range of 0 to 1. The obtained outcomes and corresponding modifications are illustrated in Figure 7.

Upon examining Figure 7, it was determined that A2 was the best whey protein alternative, while A7 was ranked the lowest for all values of v. The study concluded that the rankings of A3, A5, and A6 were sensitive to the value of v. Specifically, for v values of 0.9 and 1.0, A3 was ranked third, while for other v values, it was ranked fourth. Similarly, A5 was ranked third for v values of 0.0, 0.1, 0.2, and 0.3 but was ranked second for other v values.

The results obtained from evaluating the ranking of alternatives with varying criterion weights are presented in Figure 8. Each criterion was evaluated individually by all decision-makers, ranging from EHI to ELI. During this stage, the evaluation results for the remaining criteria remained constant. A total of 81 different situations were evaluated, resulting from the assessment of 9 criteria using 9 different linguistic evaluations. Upon examining the figure, it is evident that the A2 alternative was ranked as the most favorable option, while the A7 alternative was determined to be the least favorable, regardless of the varying criterion weights. It was also observed that the rankings of the top three alternatives remained consistent, despite changes in the criteria weights. Regarding the A1, A3, and A4 alternatives, it was found that changes in the weights of certain criteria caused alterations in their rankings. Specifically, when the mixing performance and calorie criteria were evaluated with VLI or ELI values, the ranking of the A4 alternative decreased to 6th and 5th place, respectively, based on these criteria. Additionally, when the A3 alternative was assessed in terms of the price and mixing performance criteria, it was ranked lower compared to the other criteria evaluated.

4.5. Comparison Analysis

In this part of the study, the results obtained by the VIKOR method based on circular intuitionistic fuzzy sets will be compared with the results obtained from different multi-criteria decision-making methods.

When the same problem was solved with TOPSIS based on circular intuitionistic fuzzy sets, A2 was determined as the best whey protein powder. The problem was solved with different multi-criteria decision-making methods based on triangular fuzzy numbers (TFN), and the results shown in Table 13 were obtained.

It was observed that the second alternative was always the best result when the problem was handled with different fuzzy number sets and different methods. However, there were some minor changes because of closeness coefficients in the ranking of the other alternatives. When Spearman's rank correlation coefficient was calculated, it was found as 0.964 between fuzzy VIKOR and fuzzy TOPSIS, and 0.857 between fuzzy VIKOR and all other methods. It has been easily observed that there is a strong and positive relationship between the proposed method and other methods.

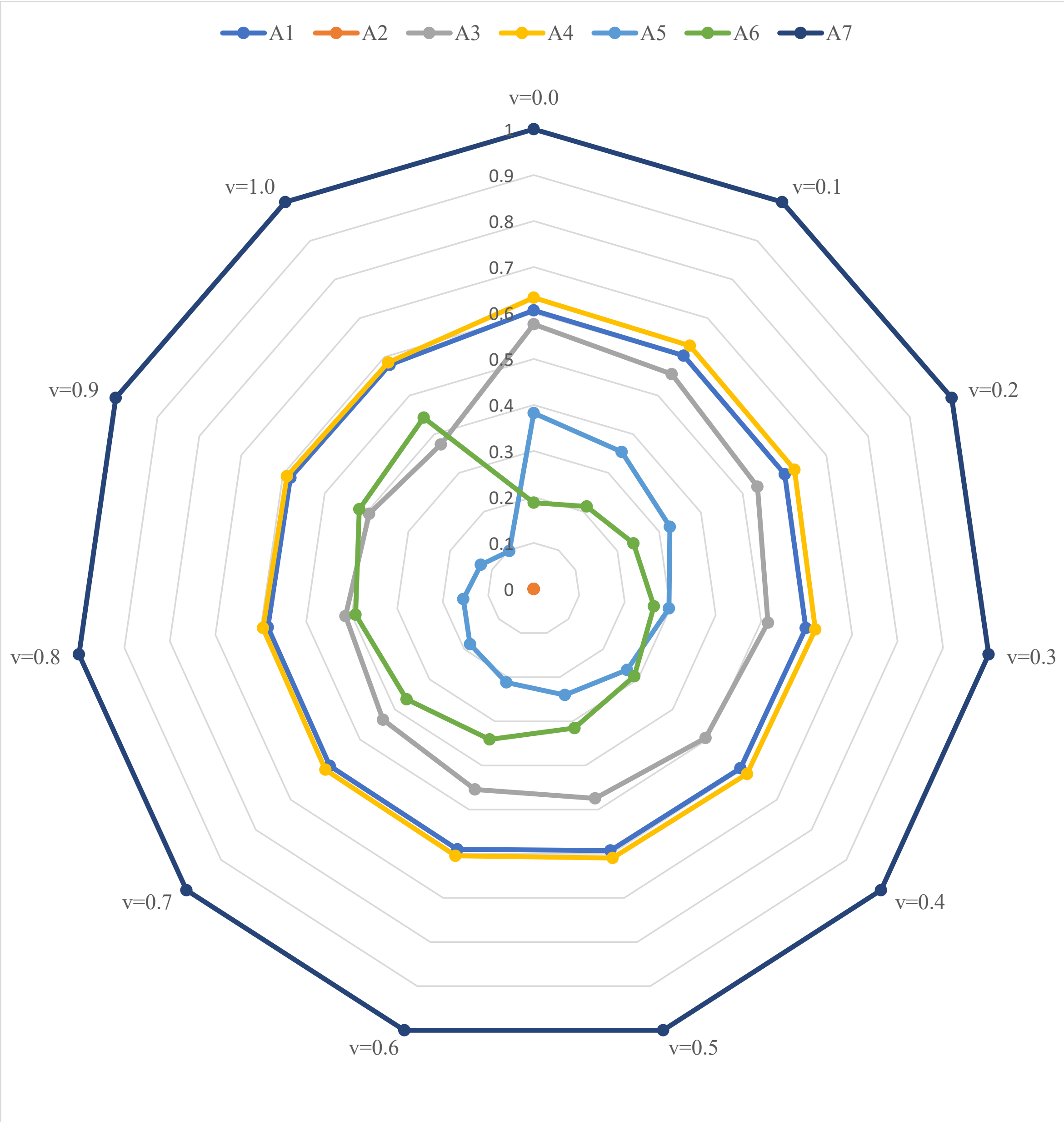

Figure 7. $\overline{Q}$ values for different v values.

Table 13. Comparison of alternatives' ranking according to different MCDM methods.

Methods	Ranking
Fuzzy VIKOR based on C-IFS	A2 > A5 > A6 > A3 > A4 > A1 > A7
Fuzzy TOPSIS based on C-IFS	A2 > A6 > A5 > A3 > A4 > A1 > A7
Fuzzy ARAS based on TFN	A2 > A5 > A3 > A6 > A1 > A7 > A4
Fuzzy EDAS based on TFN	A2 > A5 > A3 > A6 > A1 > A7 > A4
Fuzzy COPRAS based on TFN	A2 > A5 > A3 > A6 > A1 > A7 > A4
Fuzzy CODAS based on TFN	A2 > A5 > A3 > A6 > A1 > A7 > A4
Fuzzy MOORA based on TFN	A2 > A5 > A3 > A6 > A1 > A7 > A4

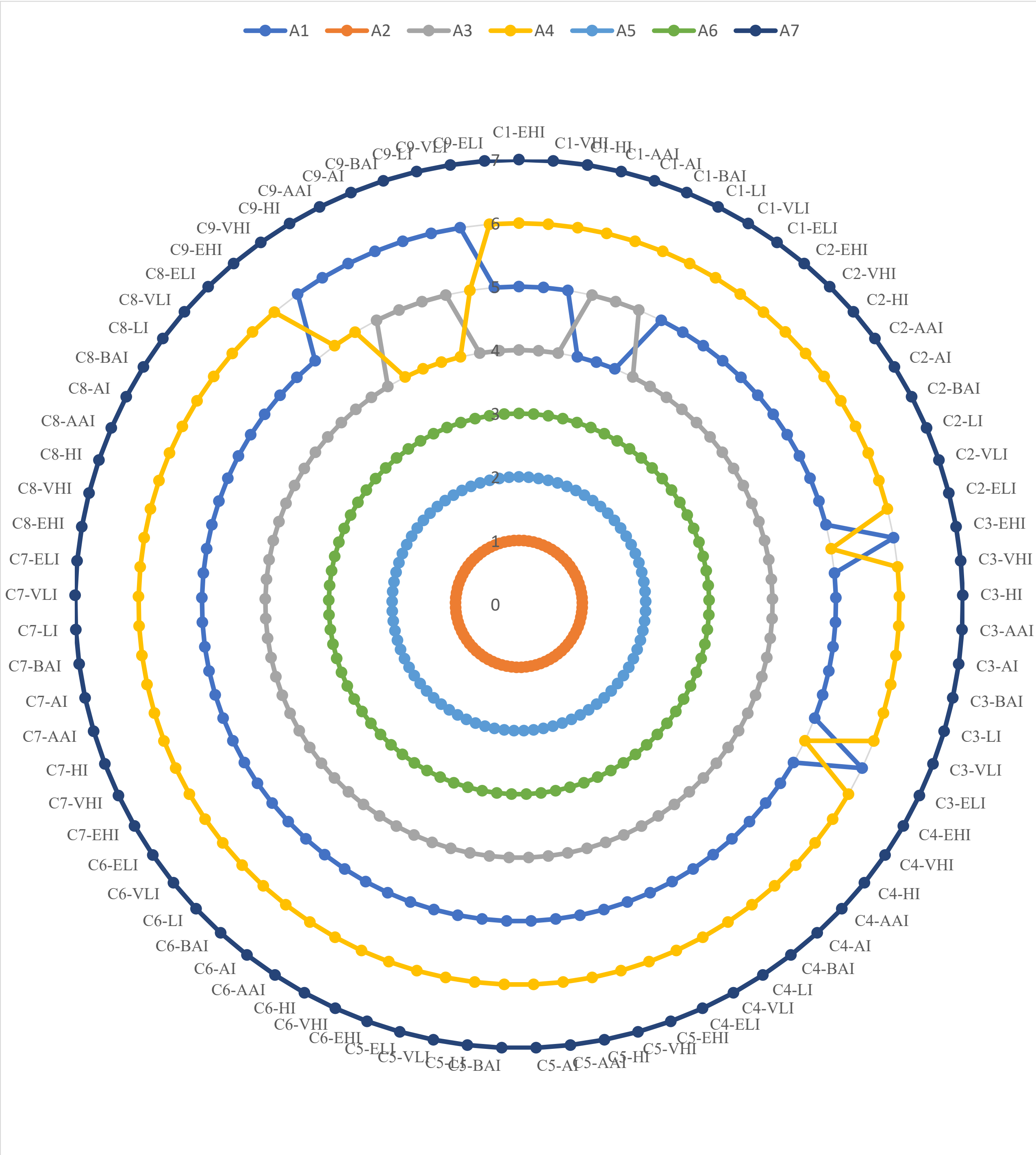

Figure 8. Ranking of alternatives for different criteria weights.

As a result, VIKOR is a multi-criteria decision-making method that provides an effective and compromise solution. Compared to other methods, the utility weight is used in the VIKOR method. This utility weight also varies depending on the attitude of the decision-makers. Circular intuitionistic fuzzy sets are also preferred because they are easier to understand and computationally simple compared to other fuzzy sets.

5. Conclusions

Individuals want to have a symmetrical, smooth, and strong body for many different reasons. Regular exercise activities are the basis of having a body with the specified features.

However, protein powders used with exercise also help individuals support this process. However, there are too many products in the market and individuals may hesitate to choose the right one. In this study, the most important criteria to be considered in the selection process and the best alternative according to these criteria were determined.

This study addresses the problem of selecting the most effective and efficient whey protein powder available in the market by utilizing the VIKOR method, which is based on circular intuitionistic fuzzy sets. The use of C-IFS enables the consideration of uncertainties that may arise during the evaluation process conducted by the decision-making team. Various sensitivity analyses were conducted to examine the responses of the alternatives.

The study was conducted as a result of the evaluations obtained by individuals living in Turkey, participating in amateur or professional sports, and using protein powder. Working on a regional scale can be shown as a limitation of this study. In the evaluations, the price of the product was determined as the most important criterion, and the amount of protein and sugar was determined as the second and third criteria. The result of this shows that individuals living in Turkish conditions give importance to price first when making a choice in the face of high inflation and high cost of living. It is highly probable that the result will be different if this study is conducted among individuals with high-income levels. When price is the most important criterion, it is natural to obtain the second alternative, which is rich in protein and low in sugar, as the best whey protein powder.

In future studies, the same problem could be addressed using different divergence measures, and the results obtained could be compared. The criteria affecting the selection process can be expanded. Furthermore, the same problem could be tackled with various MCDM methods. In addition, it will be possible to reach more objective results with a decision-maker team that can be established on an international scale.

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Symbol and Abbreviations

C-IFS	circular intuitionistic fuzzy set
U	universal set
I	intuitionistic fuzzy set
I'	circular intuitionistic fuzzy set
ɱ$_I$	the membership degree
¥$_I$	the non-membership degree
$\hbar_I$	the degree of hesitancy
r	radius
E_k	the set of experts
w_k	the weight of experts
M	the circular intuitionistic fuzzy set matrix
w_j	the weight of the criteria
D	divergence measure
PI_j	positive ideal circular intuitionistic fuzzy values
NI_j	positive ideal circular intuitionistic fuzzy values
$\overline{S}$	the group utility index
$\overline{R}$	the individual regret index
$\overline{Q}$	the compromise index
m	the number of alternatives
X'	the first minimum value in the $\overline{Q}$ list
X''	the second minimum value in the $\overline{Q}$ list

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