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Assessment of milk-based high protein products as ingredients of low-fat ice creams

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Abstract

Background and Objective: This study assessed the potential of incorporating high-protein dairy ingredients into ice cream recipes in response to increasing consumer interest in high-protein foods with improved nutritional benefits. The goal was to assess the functional and compositional characteristics of protein ingredients derived from skim milk, which could play a critical role in creating low-fat ice cream that meets sensory expectations.

Material and Methods: Various milk-based protein ingredients, including milk protein concentrate, rennet casein, acid casein, sodium caseinate, calcium caseinate, and micellar casein concentrate, have been analyzed for their protein content, ash content, amino acid profiles, and functional characteristics such as water-binding and viscosity-building capacities. This comprehensive assessment was conducted to assess their potential to replicate the creamy texture of traditional ice creams.

Results and Conclusion: The protein content of the ingredients varied from 82.5–92.7%, with acid casein and sodium caseinate showing the highest levels. This high protein content contributed to excellent water-binding and viscosity-building characteristics, which are critical for replicating the creamy texture of ice creams. Rennet casein and sodium caseinate included higher ash contents, which could affect the ice creams' mineral content and overall flavor profile. Although milk protein concentrate, sodium caseinate, and micellar casein concentrate lacked certain essential amino acids, they included biological values of over 50%, thereby enhancing the nutritional quality of low-fat ice cream formulations. The potential of these high-protein dairy ingredients to significantly affect the development of healthier ice cream products with desirable sensory and physicochemical characteristics cannot be exaggerated. Incorporating these ingredients into low-fat ice cream offers a promising approach to creating further nutritious products.

Conflict of interest: The authors declare no conflict of interest.

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1. Introduction

Ice cream is one of the most famous frozen desserts used in most countries. According to the FDA (2014), ice cream should contain more than 10% milk fat or 10% non-fat milk solids [1]. If fat content limitations are modified in recipes, high-protein dairy-based ingredients can be used instead of milk fat. Modern technologies in the dairy industry, including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and ion exchange (IE), have made it possible to achieve a wide range of high-protein ingredients with specific functional and technological characteristics that can optimize composition and technological aspects of food production [2,3].

In addition to the functionality of dairy-based ingredients for food uses (water binding and viscosity building; emulsification; flavor enhancement; gelling and heat setting; whipping, foaming, aeration, and so on), milk proteins include excellent nutritional value [4]. Due to their distinctive physiological characteristics, high protein ingredients are vital compounds of functional and specialized foods for various age groups, ranging from infant formulations to elderly nutrition [5,6]. Research worldwide verifies the benefits of high-protein diets in weight management, glycemic index regulation, bone health maintenance, muscle loss prevention, and sarcopenia risk [7–9].

Moreover, modern trends in healthy eating guide consumers to consume foods with high protein content. In 2020, foods with high protein content accounted for nearly 50% of the consumer market [10]. Increased consumer demand for high-protein foods derives innovation in industrial production, addressing the diversity of dairy ingredients and knowledge of their functional characteristics and nutritional values [11].

Expansion of the range of products with increased protein contents is associated with the priority criteria for consumers to choose food products, including attractive organoleptic characteristics, low-calorie contents, health benefits, and safety. Thus, ice creams with decreased fat due to increased protein content should include specified organoleptic characteristics and high biological values [12, 13]. This study collected data on high-protein dairy-based ingredients and technological aspects of their production, as well as functional and technological characteristics that could affect quality indicators of low-fat ice creams. It also compared their nutritional values, focusing on amino acid composition.

2. Materials and Methods

2.1 Materials

Although skim milk is a secondary resource, it is rich in nutrients, particularly protein, allowing it to produce a wide range of high-protein ingredients with increased nutritional values. Samples of high-protein ingredients were made by foreign manufacturers (Lithuania and Australia) and supplied by Unifood, St. Petersburg, Russia [14]. Chemical compounds (Table 1 and Figure 1) and functional-technological characteristics (Table 2) of high-protein dairy-based ingredients were:

- Milk protein concentrate (MPC)
- Casein such as rennet casein (RC) and acid casein (AC)
- Caseinates such as sodium caseinate (SC) and calcium caseinate (CC)
- Micellar casein concentrate (MCC)

2.2 Methods

2.2.1 Protein and amino acid analyses [15]

The energy values of high-protein ingredients were calculated using coefficients of the energy values of nutrients, such as 3.8 kcal.g^{-1} for proteins and carbohydrates and 8.9 kcal.g^{-1} for fats.

The National Standard of the Russian Federation (NSRF) 55577-2013 was used to assess the energy values of the high-protein ingredients based on skim milk. This standard is entitled “specialized and functional food products. Information on distinctive features and efficiency” [16]. According to NSRF 55577-2013, a high-protein product must provide at least 20% of the energy value from proteins. To calculate the amino acid score, the content of each essential amino acid of the investigated ingredient was compared with its content in the reference protein (FAO WHO, 2011) by Eq. 1:

$$Amino\ acid\ score = A_x\ /\ A * 100 \qquad \text{Eq. 1}$$

Where, Ax was the mass fraction of an essential amino acid of the investigated ingredient, g.100g^{-1} protein, and A was the mass fraction of an essential amino acid in the reference protein, g.100g^{-1} protein.

Table 1. Chemical compositions of the high-protein ingredients based on skim milk. [Original Table by Authors]

Constituents	Composition of high-protein dairy-based ingredients, %					
	MPC	RC	AC	SC	CC	MCC
Protein	82.5	84.0	92.0	92.7	88.0	83.0
Fat	1.0	1.5-2.0	1.0	0.7	2.0	1.0
Lactose	2.5	0.6-1.0	0.5	0.3	0.7	1.0
Ash	6.6	7.5-8.0	2.4	3.0	5.0	7.8
Moisture	5.0	10.0-12.0	10.0	4.3	5.0	5.0
Calcium	2.1	-	0.03	0.03	0.85	2.3
Phosphorus	1.6	-	1.25	1.23	1.1	1.7
Sodium	<0.05	-	<0.05	1.12	<0.05	<0.05

Source: Suthar J, Jana A, Balakrishnan S. High protein milk ingredients-A tool for value-addition to dairy and food products. J Dairy Vet Anim Res. 2017;6:00171. doi: https://doi.org/10.15406/jdvar.2017.06.00171

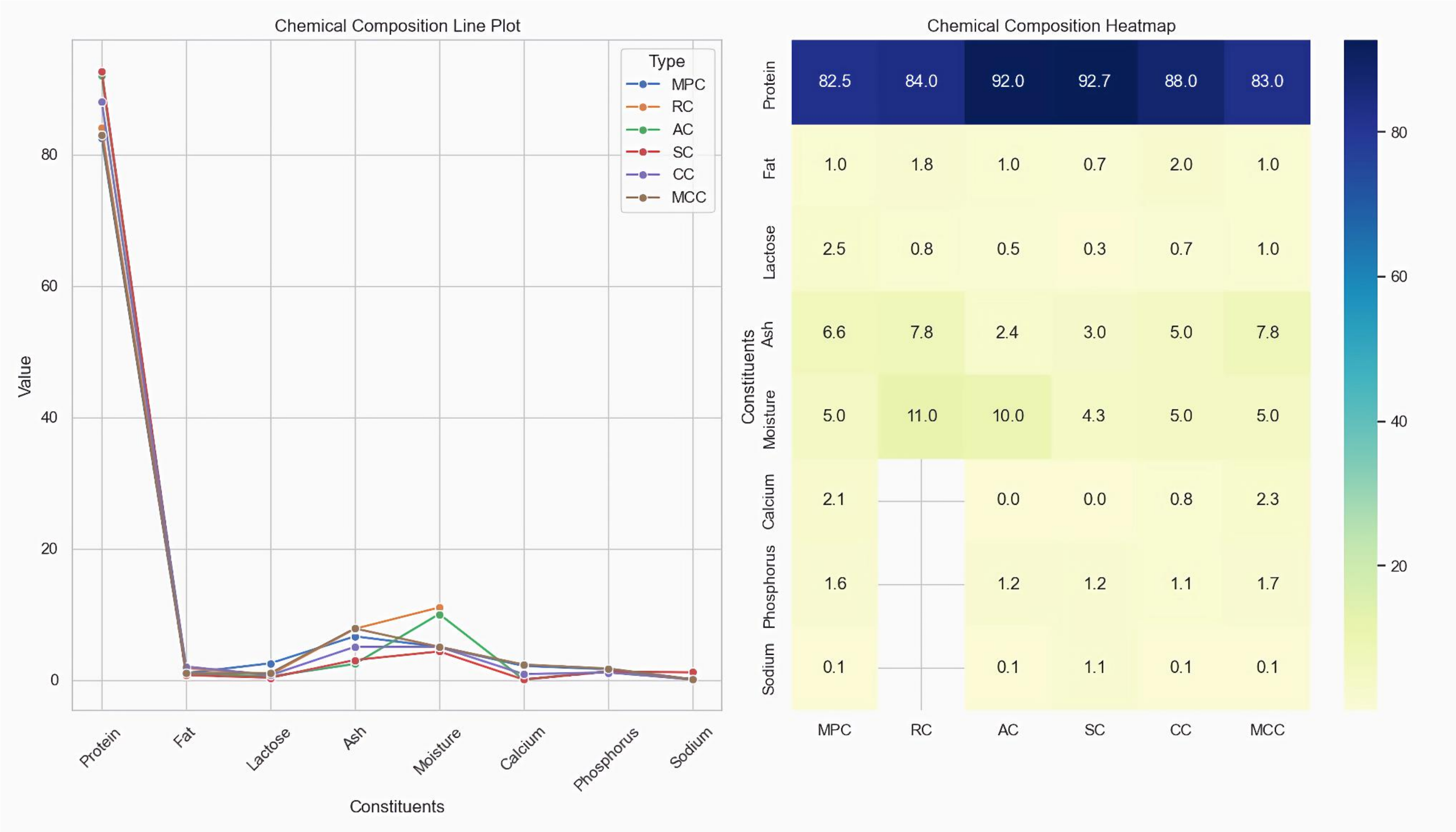

Figure 1. Chemical compositions of the protein concentrates. The line plot on the left shows values of essential components such as protein, fat, lactose, ash, moisture, calcium, phosphorus, and sodium in various types of MPC, RC, AC, SC, CC, and MCC. Protein content was significantly higher than other components, while fat and lactose levels were comparatively low. The heatmap on the right offers a further intricate perspective of the chemical composition, revealing that protein content ranged from 82.5–92.7%, with AC and SC showing the highest concentrations. Other components, such as fat, lactose, and sodium, were present in much smaller quantities, with significant variations in ash and moisture content among the types. This comparison underscored the significance of the protein in these concentrates, with diversity in minor components affecting their nutritional makeup. [Original Illustration by Authors]

Table 2. Functional-technological characteristics of the high-protein ingredients based on skim milk. [Original Table by Authors]

Functional-technological properties	Benefit
Solubility	It prevents sedimentation in beverages, soups, and sauces.
Emulsification	Prevents fat globules from forming lumps; improves product appearance.
Browning/ Color	Accentuates color development during cooking and baking; enhances opacity in low-fat foods.
Gelling/ Heat setting	It improves mouthfeel and provides a creamy, smooth fat texture in low-fat products.
Water binding/ viscosity building	It provides fat-like attributes, allows fat reduction, and improves texture.
Whipping/ Foaming/ Aeration	Maintains foam properties for visual appeal, taste, and texture.
Wetting	Improves dispersibility in dry drink mixes; prevents clumping.
Dispersibility	Ensures uniform mixing in liquid formulations
Heat stability at neutral pH	Suitable for heat-processed foods; maintains stability at high temperatures.
Viscosity	Ensures desired thickness in sauces and soups.
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Source: Suthar J, Jana A, Balakrishnan S. High protein milk ingredients-A tool for value-addition to dairy and food products. J Dairy Vet Anim Res. 2017;6:00171. doi: https://doi.org/10.15406/jdvar.2017.06.00171, Sharma A, Jana AH, Chavan RS. Functionality of milk powders and milk-based powders for end use applications—a review. Comprehensive reviews in food science and food safety. 2012;11(5):518-28. doi: https://doi.org/10.1111/j.1541-4337.2012.00199.x

An amino acid with a scoring rate of less than 100% was called "limiting." In the presence of several limiting amino acids in the composition of the product/ingredient, the amino acid with the lowest amino acid score was called the "first limiting amino acid." The biological value of the protein component was assessed using Eqs. 2–4 suggested by Professors I. A. Rogov and N. N. Lipatov, which included coefficients of differences of the amino-acid score (CDAAS, %) and biological value (BC, %). In particular, CDAAS (%) showed the average excess of the amino acid score of essential amino acids, compared to the lowest score of an essential amino acid.

$$CDAAS = \frac{\sum \triangle DAAS}{n} \quad \text{Eq. 2}$$

Where, ΔDAAS was the difference between the amino-acid score calculated based on Eq. 3 and n was the number of essential amino acids.

$$\triangle\, DAAS = C_i - C_{min} \quad \text{Eq. 3}$$

Where, C_i was the score of "i" th essential amino acid (%), and C_{min} was the minimum score of essential amino acids (%). The protein component's biological value (BV) was assessed using Eq. 4.

$$BV = 100 - CDAAS, \% \quad \text{Eq. 4}$$

3. Results and Discussion

3.1 High-protein Composition and Energy Value

Analysis of high-protein ingredients derived from skim milk, following NSRF 55577-2013 standards, verifying that all the samples were qualified as high-protein products, contributing more than 20% of their total energy value from protein (Table 3 and Figure 2). Sodium caseinate (SC) varied, offering the highest energy value at 360.4 kcal.100g^{-1}, closely followed by acid casein (AC) at 359.6 kcal.100g^{-1}. Protein contributes over 95% of the total caloric content in most samples, underscoring its significance (Figure 2) [4]. These characteristics make these ingredients excellent candidates for high-protein formulations, particularly in low-fat ice creams, where nutritional value is critical without compromising sensory appeal. SC and AC emerge as the top performers when breaking down the protein content, with protein concentrations reaching 92.7% and 92.0%, respectively. Although lactose and fat contents were minimal, they varied within the samples. For example, SC included the lowest lactose content (0.3%), while RC (rennet casein) included the highest fat content (up to 2.0%) [17]. These differences were more than nutritional details alone, as they affected the functional roles of the ingredients in food products.

3.2 Protein and Amino Acid Composition

In addition to total protein content, the amino acid composition of these high-protein ingredients is critical to their nutritional quality. Compared to FAO/WHO 2011 standards, a rich profile of essential amino acids (EAA) is seen (Table 4 and Figure 3). For example, micellar casein (MCC) and milk protein concentrate (MPC) delivered high levels of leucine (9.8 g.100g^{-1} protein for MCC) and lysine (7.90 g.100g^{-1} protein for MCC), which are vital for muscle growth and repair [18]. However, RC was limited by its lower lysine content, which decreased its overall biological value (BV) compared to other ingredients (Figure 3). The biological value of these protein ingredients varied significantly. The MCC, MPC, and SC were particularly advantageous, as they lacked limiting amino acids, resulting in biological values of 58.19, 72.23, and 75.35%, respectively. These characteristics make them highly appropriate for enriching the protein content of low-fat ice creams, which aims to enhance nutritional value without losing quality (Table 5) [19,20].

3.3 Biochemical Pathways and Production Processes

The high-protein ingredients analyzed were produced through various biochemical and biotechnological processes such as coagulation, ultrafiltration, and dehydration (Figure 4). These methods included distinct products with specific functional characteristics. For example, caseinates produced through enzymatic or acid coagulation include excellent emulsifying and gelling characteristics, making them ideal for improving the texture and mouthfeel of ice creams [21]. The SC and AC, known for their high protein content, include unique water-binding and viscosity-enhancing capabilities. These characteristics are key for replicating the creamy texture of full-fat ice creams in low-fat versions, ensuring that the final product still appeals to consumers despite decreased fat content [22,23].

Table 3. Energy values of the high-protein ingredients based on skim milk. [Original Table by Authors]

Constituents	Composition of high-protein dairy-based ingredients, %					
	MPC	RC	AC	SC	CC	MCC
Protein	82.5	84.0	92.0	92.7	88.0	83.0
Fat	1.0	1.5-2.0	1.0	0.7	2.0	1.0
Lactose	2.5	0.6-1.0	0.5	0.3	0.7	1.0
Energy value	331.9	337.8*	360.4	359.6	354.9	328.1
Energy value of the ingredient due to protein, kcal/100g	313.5	319.2	349.9	352.3	334.4	315.4
Energy value of the ingredient due to protein, %	94.5	94.3*	97.0	98.0	94.2	96.0

* Average value

Table 4. Amino acid compositions of the high-protein ingredients based on skim milk*. [Original Table by Authors]

Essential amino acids (EAA)	Mass fraction of EAA, g / 100g protein*						
	FAO / WHO, 2011	MPC	RC	AC	SC	CC	MCC
Histidine	2.00	2.60	2.20	2.50	2.60	2.70	3.20
Isoleucine	3.20	4.40	3.80	4.60	4.50	4.00	5.20
Leucine	6.60	8.60	7.50	8.20	7.80	7.00	9.80
Lysine	5.70	7.10	3.20	7.20	6.20	6.90	7.90
Methionine + Cysteine *	2.70	3.00	4.00	2.20	2.80	2.60	3.50
Phenylalanine + Tyrosine *	5.20	8.80	8.90	9.10	8.50	8.00	11.00
Threonine	3.10	3.90	3.60	3.80	3.90	3.10	6.60
Tryptophan	0.85	1.60	1.10	0.70	1.30	0.60	1.90
Valine	4.30	5.70	5.00	5.00	4.80	4.40	6.70

Source: Consultation F. Dietary protein quality evaluation in human nutrition2011. 1-66 p. Available from: https://openknowledge.fao.org/handle/20.500.14283/i3124e.

Table 5. Biological values of the high-protein ingredients based on skim milk (FAO WHO, 2011). [Original Table by Authors]

Essential amino acids (EAA)	Amino-acid score, %					
	MPC	RC	AC	SC	CC	MCC
Histidine	130.00	110.00	125.00	130.00	135.00	160.00
Isoleucine	137.50	118.70	143.75	140.60	125.00	162.50
Leucine	130.30	113.60	124.24	118.20	106.10	148.48
Lysine	124.60	56.10**	126.32	108.77	121.05	138.60
Methionine + Cysteine	111.00*	148.10	81.48***	103.70*	96.30**	129.63*
Phenylalanine + Tyrosine	169.00	171.20	175.00	163.46	153.85	211.54
Threonine	125.80	116.10	122.58	125.81	100.00	212.90
Tryptophan	188.20	129.40	82.35**	152.94	70.59***	223.53
Valine	132.50	116.30	116.28	111.63	102.33	155.81
CDAAS, %	27.77	63.80	39.30	24.65	41.66	41.81
BV, %	72.23	36.15	60.70	75.35	58.34	58.19

* Essential amino acid with a minimum score
** Limiting essential amino acid

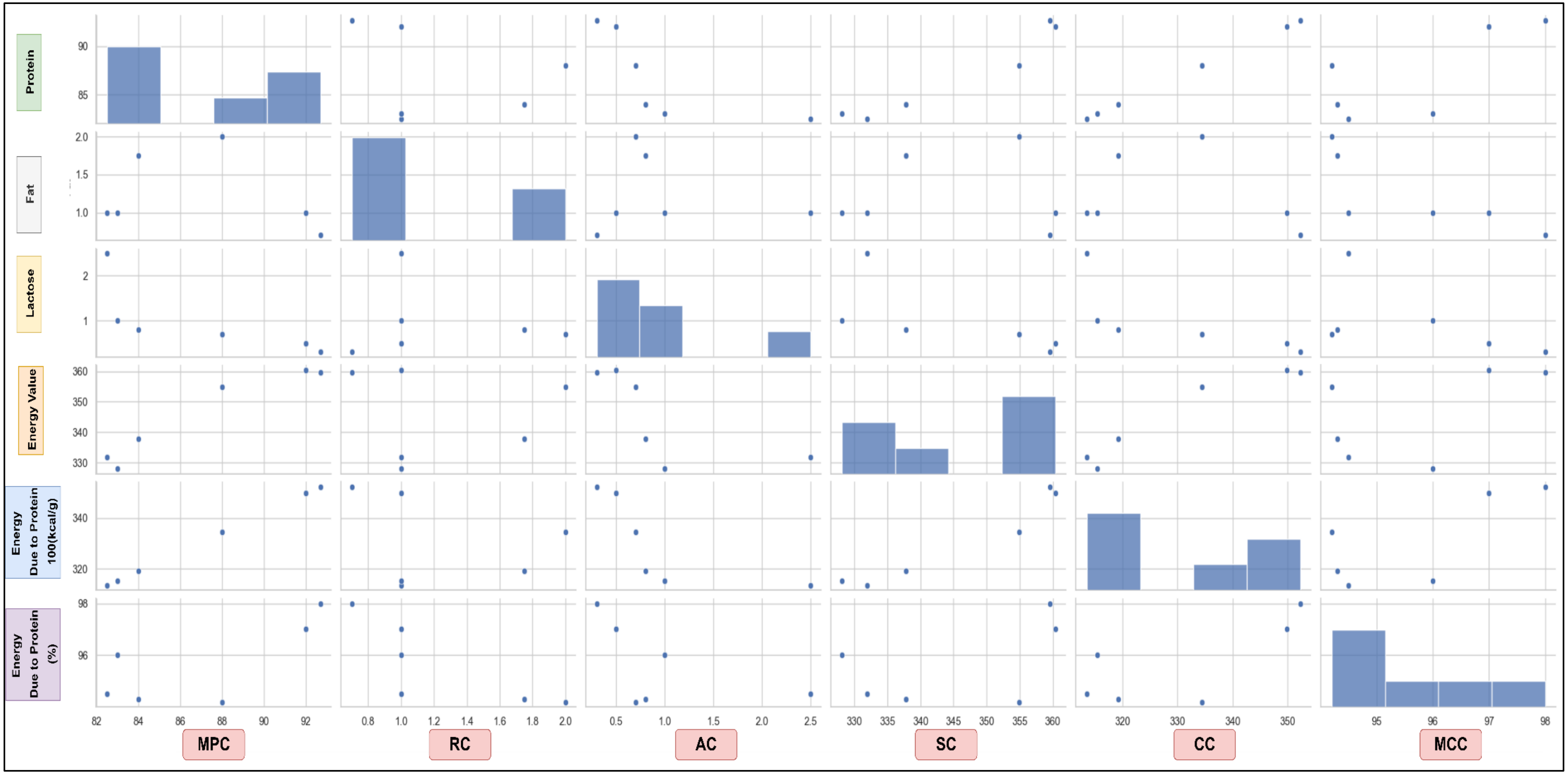

Figure 2. Nutritional and energy compositions of the high-protein ingredients based on skim milk. The figure illustrates distributions of protein, fat, lactose, energy value, and energy derived from protein within various MPC, RC, AC, SC, CC, and MCC protein sources. Histograms and scatter plots demonstrate the variability and distribution of each component. Protein content ranged from 82–92% in all sources with minimal but various levels of fat and lactose, particularly for SC and RC. The energy value (kcal/100 g) was strongly correlated to protein content, with SC showing the highest energy value at 360 kcal/100 g. Energy contribution from proteins consistently exceeded 95% for most sources, indicating the dominance of proteins in the overall caloric content. Scatter plots highlight outliers and variability within the dataset, providing insights into the composition of each protein source. [Original Illustration by Authors]

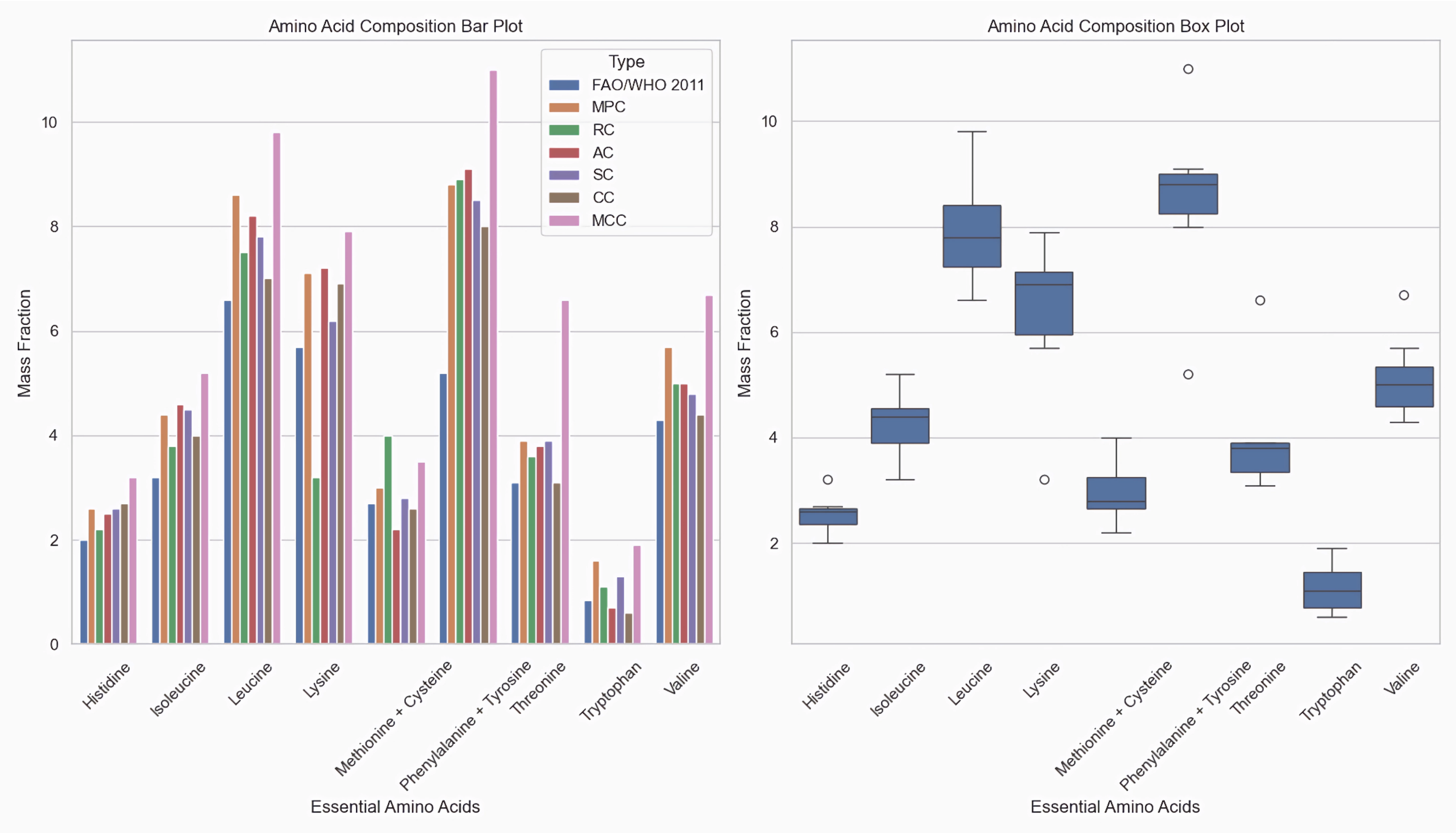

Figure 3. Amino acid compositions of the high-protein ingredients based on skim milk. The bar plot on the left illustrates the mass fraction of the essential amino acids (histidine, isoleucine, leucine, lysine, methionine, cysteine, phenylalanine, tyrosine, threonine, tryptophan, and valine) in various protein sources such as FAO/WHO 2011, MPC, RC, AC, SC, CC, and MCC. On the right, the box plot shows the distribution and variability of amino acid mass fractions within these sources. Each amino acid shows distinct variability, with leucine, lysine, and valine demonstrating the most extensive spread in mass fraction values and highlighting differences in protein source composition. Individual points outside the whiskers are outliers. [Original Illustration by Authors]

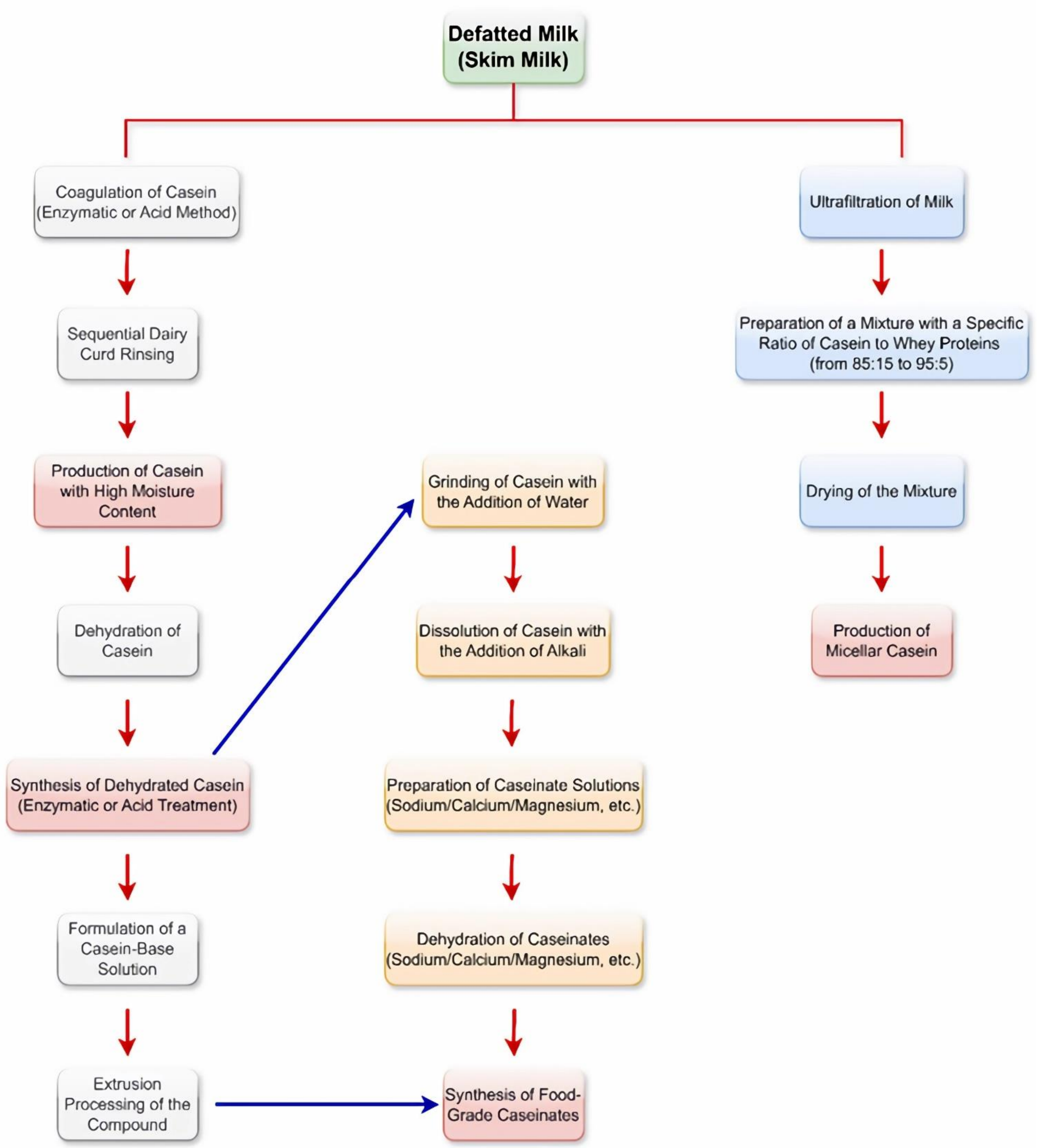

Figure 4. Technological scheme of the high-protein ingredient production from skim milk. The diagram shows two distinct pathways for extracting and processing casein and its derivatives from defatted milk (skim milk). The first pathway (left) involves the coagulation of casein using an enzymatic or acid method, followed by curd rinsing, dehydration, and synthesis into a casein-based solution. Extrusion processing is then used for the final product formulation. The second pathway (right) includes the production of food-grade caseinates through the processes of grinding and dissolution of casein, preparation of caseinate solutions (e.g., sodium, calcium, and magnesium), and dehydration. Furthermore, the production of micellar casein involves ultrafiltration and drying of a casein-to-whey protein mixture with specific ratios (85:15 to 95:5). The flowchart emphasizes variations in processing methods used to produce various casein-based products, including food-grade caseinates and micellar casein. [Original Illustration by Author]

3.4 Physicochemical and Sensory Effects

The type and concentration of high-protein ingredients profoundly affect the physicochemical characteristics of low-fat ice creams. Proteins, especially SC and MCC, play critical roles in binding water and creating emulsions, which are essential for maintaining the desired texture and stability. These ingredients help control ice crystal growth during freezing and storage and contribute to smoother, further homogenous products (Table 1) [24,25]. From a sensory perspective, these proteins' ability to prevent fat globules from coalescing enhances the overall appearance and mouthfeel of the ice cream. For example, MPC provides a balanced combination of protein and fat that smooths the texture without introducing off-flavors that can occur with proteins high in ash content, such as RC and SC [26–28]. Furthermore, the gelling capability of SC contributes to a firmer structure, which is critical for product stability over time [29].

3.5 Functional and Technological Benefits

Functional characteristics of high-protein ingredients are more significant than simple nutritional improvements as they are essential for maintaining the quality of low-fat ice creams during processing and storage. Characteristics such as solubility, dispersibility, and heat stability at neutral pH are critical for ensuring product integrity [30]. For example, excellent solubility of these proteins prevents sedimentation and helps maintain uniformity of the final product. Additionally, their emulsifying characteristics ensure that fat is evenly distributed, preventing separation and enhancing texture [31]. These protein water-binding and viscosity-enhancing capabilities allow for significant fat decrease without losing the creamy smooth textures that consumers expect. This is particularly important as demand increases for lower-calorie options that do not compromise taste [32]. Furthermore, the ability of these ingredients to contribute to browning and color development during cooking enhances the visual appeal of ice creams, making them further attractive to consumers [33,34].

3.6 Challenges and Limitations

Despite the advantages of using high-protein dairy ingredients in low-fat ice creams, challenges are still reported. One significant issue includes the potential for off-flavors, particularly with higher ash-content ingredients such as RC and SC. These off-flavors can negatively affect the overall taste profile of the ice creams, making it essential to carefully select and combine ingredients to achieve the desired flavor [35]. Additionally, ingredients such as RC with higher moisture content can affect the ice cream texture and decrease its shelf life, needing formulation adjustments [36].

3.7 Future Directions

The results of this study highlight several opportunities for further studies. One opportunity includes the synergistic effects of combining various protein types to optimize low-fat ice cream's sensory and physicochemical characteristics. Investigating how protein modifications such as enzymatic treatments or cross-linking that further improve functionality can lead to further versatile uses of these ingredients [37,38]. Addressing off-flavors and moisture content challenges is a priority for improving product quality. Innovations in biotechnology, including advanced ultra-filtration techniques and enzymatic modifications, offer promising ways to develop better high-protein ingredients that meet nutritional and sensory expectations [39,40]. Further studies in this field will likely lead to additional innovative solutions that align with consumer preferences for healthier, more enjoyable food options [41].

4. Conclusion

In conclusion, incorporating high-protein dairy-based ingredients into low-fat ice cream formulations offers a promising approach to creating healthier dessert options that retain desirable sensory and physicochemical characteristics. These ingredients can be designed to enhance texture, stability, and overall quality using modern biotechnological processes such as ultrafiltration and enzymatic treatments. Comparative analysis of various high-protein ingredients highlights their unique contributions, with sodium caseinate and micellar casein high-lighting their exceptional water-binding, gelling, and emulsification characteristics. While challenges e.g. managing off-flavors and moisture content are still addressed, developments of high-protein dairy ingredients provide significant opportunities for innovations in the food industry. Future studies should focus on optimizing protein blends and investigating new processing techniques to further enhance the appeal and functionality of low-fat ice creams. Integrating biochemistry and biotechnology in food science drives advancements that align with consumer demands for nutritious, delicious, and sustainable food products.

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6. Conflict of Interest

The authors declare no conflict of interest.

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ارزیابی فرآورده‌های شیری حاوی پروتئین بالا به‌عنوان مواد تشکیل دهنده بستنی‌های کم‌چرب

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چکیده

سابقه و هدف: به‌منظور پاسخ به افزایش علاقه مصرف‌کنندگان به غذاهای پر پروتئین با مزایای تغذیه‌ای بهبودیافته، این مطالعه با هدف بررسی امکان استفاده از فرآورده‌های شیری پر پروتئین در فرمولاسیون بستنی انجام شد.. هدف ارزیابی ویژگی‌های فراسودمندی[۱] و ترکیبی مواد پروتئینی مشتق‌شده از شیر بدون چربی بود که بتواند نقش مهمی در تولید بستنی کم‌چرب داشته باشد و ویژگی‌های حسی مورد نظر را حفظ کند.

مواد و روش ها: ترکیبات گوناگون پروتئینی برپایه شیر، شامل کنسانتره پروتئین شیر، کازئین رنت (مایه پنیر)، کازئین اسیدی، کازئینات سدیم، کازئینات کلسیم و کنسانتره میسل کازئین، از نظر میزان پروتئین و خاکستر، پروفایل اسید آمینه و ویژگی‌های فراسودمندی مانند ظرفیت اتصال آب و ویسکوزیته‌سازی مورد تجزیه و تحلیل قرار گرفتند. این ارزیابی جامع به منظور تعیین توانایی آن‌ها در بازتولید بافت خامه‌ای بستنی‌های سنتی انجام شد.

یافته‌ها و نتیجه‌گیری: محتوای پروتئین مواد تشکیل دهنده از ۸۲/۵ تا ۹۲/۷ درصد متغیر بود که کازئین اسیدی و کازئینات سدیم بالاترین میزان پروتئین را داشتند. این محتوای پروتئین بالا موجب ایجاد ویژگی‌های عالی اتصال به آب و ویسکوزیته می‌شود، که برای باز تولید بافت خامه‌ای بستنی‌ها ضروری است. کازئین رنت و کازئینات سدیم میزان خاکستر بیشتری داشتند که می‌تواند بر میزان مواد معدنی بستنی و پروفایل طعم کلی محصول تأثیر بگذارد. اگر چه کنسانتره پروتئین شیر، کازئینات سدیم و کنسانتره میسل کازئین فاقد برخی اسیدهای آمینه ضروری هستند، اما ارزش بیولوژیکی آنها بیشتر از ۵۰ درصد می‌شود و در نتیجه کیفیت تغذیه‌ای بستنی‌های کم‌چرب فرموله‌شده را افزایش می‌دهد. پتانسیل این مواد تشکیل دهنده شیری پر پروتئین تأثیر قابل توجهی بر توسعه محصولات بستنی سالم‌تر با ویژگی‌های حسی و فیزیکوشیمیایی مطلوب اغراق آمیز نیست. استفاده از این مواد در بستنی کم‌چرب رویکردی امیدوارکننده برای تولید محصولات مغذی‌تر را ارائه می دهد.

تعارض منافع: نویسندگان اعلام می‌کنند که هیچ نوع تعارض منافعی مرتبط با انتشار این مقاله ندارند.

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- پروتئین رژیمی
- بستنی
- ارزش تغذیه‌ای
- بافت مواد غذایی

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