

Exploring Protein Supplements: Benefits, Risks, And Implications For Health- A Review

Surjith Meethalveedu^a, Madhan Krishnan^b, Shyamaladevi Babu^b, Ahamed Basha Abdul Bari^{**}

^aDepartment of Physiology, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam- 603103, Tamil Nadu, India.

^bFaculty of Research, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam- 603103, Tamil Nadu, India.

Abstract

Protein supplements have become a cornerstone in the modern health and wellness landscape, widely utilized by athletes, fitness enthusiasts, and individuals seeking efficient ways to meet dietary protein requirements. These products are celebrated for their contributions to muscle development, post-exercise recovery, and weight management. However, their growing popularity has raised concerns regarding potential health risks, especially when consumed excessively or without proper guidance. Over-reliance on protein supplements can lead to adverse effects such as kidney strain, cardiovascular issues, and exposure to contaminants like heavy metals. This review provides a comprehensive analysis of the different types of protein supplements, including whey, casein, plant-based, collagen, and specialized blends, highlighting their distinct benefits and associated risks. Additionally, it delves into the challenges posed by inadequate regulatory oversight and the implications for product safety and consumer health. Emerging trends in the industry, such as sustainable protein sources and personalized nutrition, are also discussed, offering insights into the future of protein supplementation. The objective of this review is to present a balanced understanding of how to maximize the advantages of protein supplements while mitigating their potential health hazards. By emphasizing informed usage and advocating for stricter quality control measures, this study aims to contribute to the responsible consumption of protein supplements, fostering better health outcomes and sustainability in dietary practices.

Keywords: Protein Supplements; Health Risks; Muscle Recovery; Nutritional Safety; Sustainable Nutrition

INTRODUCTION

Proteins are vital macronutrients essential for life, contributing to numerous biological processes that maintain overall health. They are fundamental for muscle growth and repair, facilitate enzymatic reactions, regulate hormones, and strengthen immune function. Typically, dietary protein needs are fulfilled through natural food sources, including lean meats, dairy, eggs, and plant-based options like legumes and nuts. These dietary staples have long been adequate for maintaining protein balance in the human body [1,2]. However, modern lifestyles and evolving dietary habits have significantly altered how protein is consumed. The fast-paced nature of contemporary life, coupled with an increased focus on physical fitness and appearance, has driven individuals toward more convenient nutritional solutions. The rise of fitness culture, characterized by gym memberships, athletic competitions, and body-building trends, has further amplified the demand for protein-rich products. As a result, protein supplements have emerged as a mainstream option, appealing not only to athletes and bodybuilders but also to casual fitness enthusiasts and individuals seeking weight management solutions [3]. Protein supplements, which include a wide variety of products such as whey protein powders, casein-based formulas, collagen peptides, and plant-based shakes, represent a burgeoning global industry valued in the billions of dollars. Their popularity is rooted in their perceived benefits, including enhanced muscle growth, faster recovery from exercise, and assistance in achieving weight loss goals. Additionally, these products are marketed as convenient alternatives to whole foods, offering portability and ease of use for individuals with busy schedules or specific dietary needs [4].

Despite their widespread appeal and documented benefits, the growing reliance on protein supplements has sparked concerns about potential health risks. Overuse and improper consumption practices have been linked to a range of adverse effects, including kidney strain, cardiovascular issues, and exposure to harmful contaminants like heavy metals. The unregulated nature of the dietary supplement industry further

complicates the issue, as quality control measures are often inconsistent, and some products may contain undisclosed or unsafe ingredients [5]. This review delves into the multifaceted world of protein supplementation, examining the various types of supplements available, their respective advantages, and the potential hazards associated with their use. The discussion includes an exploration of key topics such as the regulatory challenges surrounding these products, the role of personalized nutrition in optimizing their benefits, and the emerging trends in sustainable protein sourcing. The overarching goal of this review is to provide a balanced and comprehensive perspective on protein supplements, equipping consumers, healthcare professionals, and policymakers with the knowledge needed to make informed decisions. By highlighting both the benefits and risks, this analysis aims to promote responsible usage and encourage the adoption of regulatory measures that enhance product safety and consumer health. Through a critical examination of the evolving landscape of protein supplementation, this review seeks to contribute meaningfully to the ongoing discourse on nutrition and health in modern society.

Types of Protein Supplements

Protein supplements have become increasingly popular for their role in promoting muscle development, boosting athletic performance, assisting in weight control, and offering a convenient source of nutrition. A wide range of protein options is available, each designed to cater to varying dietary preferences, health requirements, and fitness objectives. Among the most widely used are whey protein, casein protein, and plant-based proteins, each with distinct advantages and possible limitations. Gaining a clear understanding of these variations enables consumers to make well-informed choices about their supplementation in table 1 [6].

Table 1: Types of Protein Supplements – Composition, Benefits, and Risks.

Type of Protein	Composition / Sources	Key Benefits	Potential Risks Considerations	References
Whey Protein	Derived from liquid whey during cheese-making; high biological value. Forms: (1) Concentrate – 70–80% protein with fats & carbs, (2) Isolate – up to 90% protein, low lactose, (3) Hydrolysate – pre-digested for faster absorption.	Rich in BCAAs (esp. leucine), rapid digestion, ideal for post-workout recovery, promotes muscle growth, prevents muscle breakdown.	May cause digestive issues in lactose-intolerant individuals (esp. concentrate form); excessive intake may strain kidneys in people with pre-existing kidney conditions.	7, 8
Casein Protein	Comprises ~80% of milk protein; slow-digesting, forms gel in stomach, provides steady amino acid release for hours.	Prevents muscle breakdown during fasting (e.g., overnight), supports muscle repair & growth, increases satiety for weight management.	Contains lactose (can cause digestive discomfort in intolerant individuals); slower absorption not ideal for immediate post-workout recovery.	9-11

Plant-Based Proteins	Sources include soy (complete protein), pea (rich in arginine & lysine), rice (rich in cysteine & methionine), hemp (omega-3 & omega-6 rich).	Suitable for vegetarians/vegans, lactose-intolerant, and dairy-allergic individuals; easy to digest, hypoallergenic, often rich in fiber, vitamins, minerals.	Lower digestibility & bioavailability than animal proteins; possible heavy metal contamination—choose reputable brands.	12-14
Collagen Protein	Derived from animal connective tissue (skin, bones, cartilage); rich in glycine, proline, hydroxyproline; supports collagen synthesis.	Promotes skin elasticity, hydration, and joint health; aids cartilage repair; reduces wrinkles; supports injury recovery.	Generally safe; risk of allergic reactions in individuals sensitive to bovine, marine, or porcine sources verify origin before use.	15, 16
Blended / Specialized Proteins	Combination of fast- and slow-digesting proteins (e.g., whey + casein); may include plant-based blends.	Provides both immediate and sustained amino acid delivery; versatile for various fitness goals; supports quick recovery and prolonged repair.	Some blends may contain artificial sweeteners, additives, or fillers that cause digestive discomfort or long-term health concerns check labels.	17

Whey Protein

Composition and Variants

Whey protein is derived from the liquid whey produced during the cheese-making process, where it separates from the curds. It is known for its high biological value, which indicates its efficiency in promoting protein synthesis and overall nutrient absorption. Whey protein is available in three primary forms:

- **Concentrate:** This is the least processed form, containing approximately 70–80% protein. It also retains some fats and carbohydrates, including lactose. Whey concentrate is more affordable and often favored by individuals new to protein supplementation.
- **Isolate:** Whey protein isolate contains up to 90% protein and minimal amounts of fat and carbohydrates, making it suitable for those who are looking for a purer protein with fewer calories. The minimal lactose content also makes it a better option for people with lactose sensitivity.
- **Hydrolysate:** This type of protein undergoes enzymatic pre-digestion, breaking it down into smaller peptides to enable quicker absorption. Whey hydrolysate is especially advantageous for people with digestive sensitivities or for those who require rapid protein uptake, such as during post-workout recovery [7].

Nutritional Benefits

Whey protein contains a high concentration of branched-chain amino acids (BCAAs), especially leucine, which plays a key role in triggering muscle protein synthesis. Its fast digestion and absorption make it an excellent choice for post-workout recovery, delivering quick nutrient replenishment. The high-quality amino acids present in whey protein are also instrumental in promoting muscle growth and preventing muscle breakdown, making it popular among athletes and bodybuilders [8].

Potential Risks

Despite its benefits, whey protein can cause digestive discomfort in individuals with lactose intolerance. For those sensitive to lactose, the concentrate form, which retains a significant amount of lactose, may cause bloating, diarrhea, and gas. Additionally, excessive consumption of whey protein has been linked to kidney

strain in people with pre-existing kidney conditions, as the body needs to process increased amounts of nitrogen waste from protein metabolism [9].

2. Casein Protein

➤ Composition and Function

Casein protein accounts for roughly 80% of the total protein found in milk. In contrast to whey protein, it is digested at a slower rate, forming a gel-like consistency in the stomach. This gradual digestion leads to a sustained release of amino acids into the bloodstream, ensuring a steady supply of protein for several hours [10].

➤ Benefits, Risks and Considerations

The slow digestion of casein makes it an ideal protein choice for extended periods of fasting, such as during sleep. Casein is beneficial for preventing muscle breakdown (catabolism) during periods of fasting, promoting muscle repair and growth. It also has a satiating effect, which can help with weight management by reducing hunger between meals. As a result, casein is often recommended as a nighttime protein supplement to support overnight muscle recovery. Whey protein, casein also contains lactose, which may lead to digestive discomfort in people with lactose intolerance. Furthermore, its slow absorption rate might not be suitable for those who need rapid protein delivery after intense exercise. For athletes seeking rapid recovery, whey protein may be a better choice due to its faster digestion rate [11].

3. Plant-Based Proteins

Overview of Sources

Plant-based proteins serve as an effective alternative to animal-derived proteins for vegetarians, vegans, and those with lactose intolerance or dairy allergies. They are obtained from diverse plant sources, each providing distinct amino acid compositions and nutritional advantages. Common examples of plant-based protein sources include:

➤ **Soy Protein:** Soy protein is a complete protein, containing all nine essential amino acids the body needs. It is recognized for its potential health benefits, particularly due to its isoflavone content, which may possess antioxidant and anti-inflammatory effects.

➤ **Pea Protein:** Pea protein is abundant in arginine and lysine but is classified as an incomplete protein because it lacks certain essential amino acids. It is often blended with rice protein to achieve a more balanced amino acid profile.

➤ **Rice Protein:** Rich in cysteine and methionine, rice protein is deficient in the essential amino acid lysine. To make it complete, it is commonly paired with pea protein or other plant-based proteins.

➤ **Hemp Protein:** Hemp protein stands out for its high levels of omega-3 and omega-6 fatty acids, which contribute to anti-inflammatory effects. In addition to protein, it provides essential fatty acids and dietary fiber, making it a nutrient-rich choice for overall well-being [12].

Benefits for Specific Populations

Plant-based proteins are often chosen by individuals following vegetarian or vegan diets, as well as those with lactose intolerance or dairy allergies. Plant-based proteins are typically easy to digest and hypoallergenic, making them a good choice for individuals with sensitive digestive systems. Additionally, many plant-based protein powders contain high levels of fiber, vitamins, and minerals, which support overall health and wellness [13].

Challenges and Risks

One challenge with plant-based proteins is their digestibility, which may be lower than that of animal-based proteins. This can result in reduced bioavailability of amino acids, especially when compared to the highly digestible whey protein. Additionally, certain plant-based protein powders have been found to contain trace amounts of heavy metals, such as lead and cadmium, due to contamination from agricultural practices. It is important for consumers to choose reputable brands that test for contaminants to minimize these risks [14].

4. Collagen Protein

Unique Characteristics & Targeted Benefits

Collagen protein is sourced from animal connective tissues, including skin, bones, and cartilage. It contains high amounts of non-essential amino acids, especially glycine, proline, and hydroxyproline, which are essential for the body's collagen production. Collagen is key to preserving the structural strength of connective tissues, and collagen protein is commonly promoted for its positive effects on skin health, joint support, and injury recovery. Unlike other protein supplements, collagen does not significantly contribute to muscle-building but is instead used to support the body's structural framework, especially skin elasticity and joint mobility. Collagen supplementation has been found to be particularly beneficial for promoting skin elasticity and hydration, reducing wrinkles, and supporting joint function by improving cartilage and tendon health. It is commonly used by individuals seeking to reduce the appearance of aging or those recovering from joint injuries or surgeries. Research has shown that collagen protein can help increase the production of collagen in the skin, potentially reducing the visible effects of aging and improving skin strength and hydration. Additionally, collagen supports the repair of cartilage in joints, which can help alleviate pain and improve mobility, especially in individuals with osteoarthritis or joint degeneration [15].

Safety Concerns

The safety profile of collagen supplements is generally favorable, with few adverse effects reported. However, individuals with allergies to specific animal products should be cautious when selecting collagen supplements, as these are often sourced from bovine (cows), marine (fish), or porcine (pigs) collagen. It is essential to verify the source of collagen to avoid potential allergic reactions. Collagen supplements are typically well-tolerated and have minimal side effects, making them a generally safe choice for supporting skin and joint health. Nevertheless, as with any dietary supplement, it is advisable to seek guidance from a healthcare professional before beginning collagen supplementation, especially for those with certain medical conditions or allergies [16].

5. Blended and Specialized Proteins

Optimized Formulations

Blended proteins combine multiple protein sources, such as whey and casein, to provide both immediate and sustained amino acid delivery. These formulations are designed to optimize the benefits of different protein types, offering a mix of fast-digesting and slow-digesting proteins. This dual delivery system is especially beneficial for individuals who want a comprehensive protein supplement that can support both quick muscle recovery and longer-lasting muscle repair. Blended proteins are versatile and can cater to various fitness and dietary needs, making them popular among athletes, bodybuilders, and fitness enthusiasts who require a balanced protein intake for different times of the day or for specific training goals.

Customization and Risks

While blended proteins offer convenience and flexibility, consumers should be cautious about the inclusion of additives, artificial sweeteners, or other fillers. Some protein powders, especially those in blended formulations, may contain ingredients that cause gastrointestinal discomfort or other long-term health concerns. For example, artificial sweeteners such as aspartame or sucralose can lead to bloating, gas, or digestive issues in sensitive individuals. It is essential to check the ingredient list of blended protein products to ensure they do not contain unnecessary additives or fillers that could negatively affect digestion or overall health [17].

Benefits of Protein Supplements

Protein supplements provide a convenient and efficient way to meet the body's protein needs, especially in situations where whole-food sources may not be practical. The following are some of the primary benefits of protein supplementation in table 2:

Table 2: Benefits of Protein Supplements

Benefit Area	Key Mechanism / Role	Specific Applications	References

Muscle Growth & Recovery	Stimulates muscle protein synthesis (MPS) , repairing exercise-induced muscle damage and promoting growth; delivers essential amino acids (esp. leucine).	20–40 g high-quality protein post-exercise optimizes MPS. - Whey protein is superior due to rapid absorption & high leucine content.	18, 19
Weight Management	Enhances satiety by influencing hunger hormones (ghrelin ↓, peptide YY ↑); reduces appetite and overall calorie intake.	Casein protein's slow digestion curbs late-night hunger. - Sustained amino acid release reduces snacking and supports calorie control.	20
Support for Aging Populations	Counters sarcopenia (age-related muscle loss) by promoting MPS; increases muscle maintenance, strength, and mobility.	Combined with resistance training to preserve muscle mass. - Higher protein intake post-exercise improves function and quality of life in older adults.	21

1. Muscle Growth and Recovery

Role in Muscle Protein Synthesis

Protein supplements, especially whey protein, are highly effective in promoting muscle protein synthesis (MPS) the process responsible for repairing exercise-induced muscle damage and supporting muscle growth. MPS is essential for developing and preserving muscle mass, particularly following physical activity. These supplements deliver a concentrated dose of essential amino acids the fundamental components needed for muscle repair and development [18].

Comparative Studies

Studies show that consuming 20–40 grams of high-quality protein after exercise optimizes MPS, with whey protein surpassing other protein sources due to its fast absorption and high leucine content. Leucine, a branched-chain amino acid (BCAA), is especially effective in initiating MPS, making leucine-rich whey protein a popular choice for post-workout recovery [19].

2. Weight Management

Protein and Satiety

High-protein diets are associated with greater satiety compared to carbohydrate- or fat-rich diets. Protein has a powerful impact on regulating hunger hormones, including ghrelin and peptide YY, which influence feelings of hunger and fullness. By increasing satiety, protein supplements can help individuals manage their food intake, which may contribute to weight loss or weight maintenance.

Applications in Obesity Management

Casein protein, with its slow digestion, is particularly beneficial for controlling late-night hunger and preventing overeating. Due to its sustained release of amino acids, casein helps maintain a feeling of fullness for longer periods, which can reduce nighttime snacking and aid in managing calorie intake, making it especially helpful for individuals trying to lose or manage weight [20].

3. Support for Aging Populations

Combatting Sarcopenia

Sarcopenia, the age-related loss of muscle mass, is a common issue among older adults and can lead to reduced mobility, strength, and increased risk of falls. Protein supplementation, especially when combined with resistance training, has been shown to mitigate sarcopenia by promoting muscle protein synthesis and supporting muscle maintenance. Protein needs increase with age, making it important for older adults to ensure they are getting sufficient protein from their diet or supplements.

Tailored Recommendations

As people age, their ability to efficiently absorb and utilize protein decreases, necessitating tailored supplementation strategies. Consuming higher amounts of protein, particularly after exercise, can help older adults preserve muscle mass and improve physical function, leading to better mobility and overall quality of life [21].

4. Convenience for Special Diets

Addressing Nutritional Gaps & Potential Health Risks

Protein supplements provide an easy and practical option for people with dietary restrictions or limited availability of high-quality protein foods. For vegetarians, vegans, or those adhering to specific eating patterns, they offer a convenient and dependable way to meet daily protein needs. Plant-based protein powders, in particular, can help bridge nutritional gaps for individuals who avoid animal-based protein sources. Although protein supplements deliver many benefits, improper or excessive use can result in negative health effects. High protein intake, especially from supplements, may put stress on the kidneys, particularly in those with existing kidney issues. Furthermore, some protein supplements may contain harmful contaminants such as heavy metals or allergens, which can pose health risks. To ensure safety, consumers should choose high-quality products from reputable brands and use them in moderation as part of a well-balanced diet. In summary, protein supplements can support muscle building, recovery, weight control, and the nutritional needs of aging individuals. However, as with any supplement, they should be used thoughtfully, based on personal health status and requirements. By being aware of their types, advantages, and potential drawbacks, individuals can make informed choices that enhance overall health in figure 1 [22].

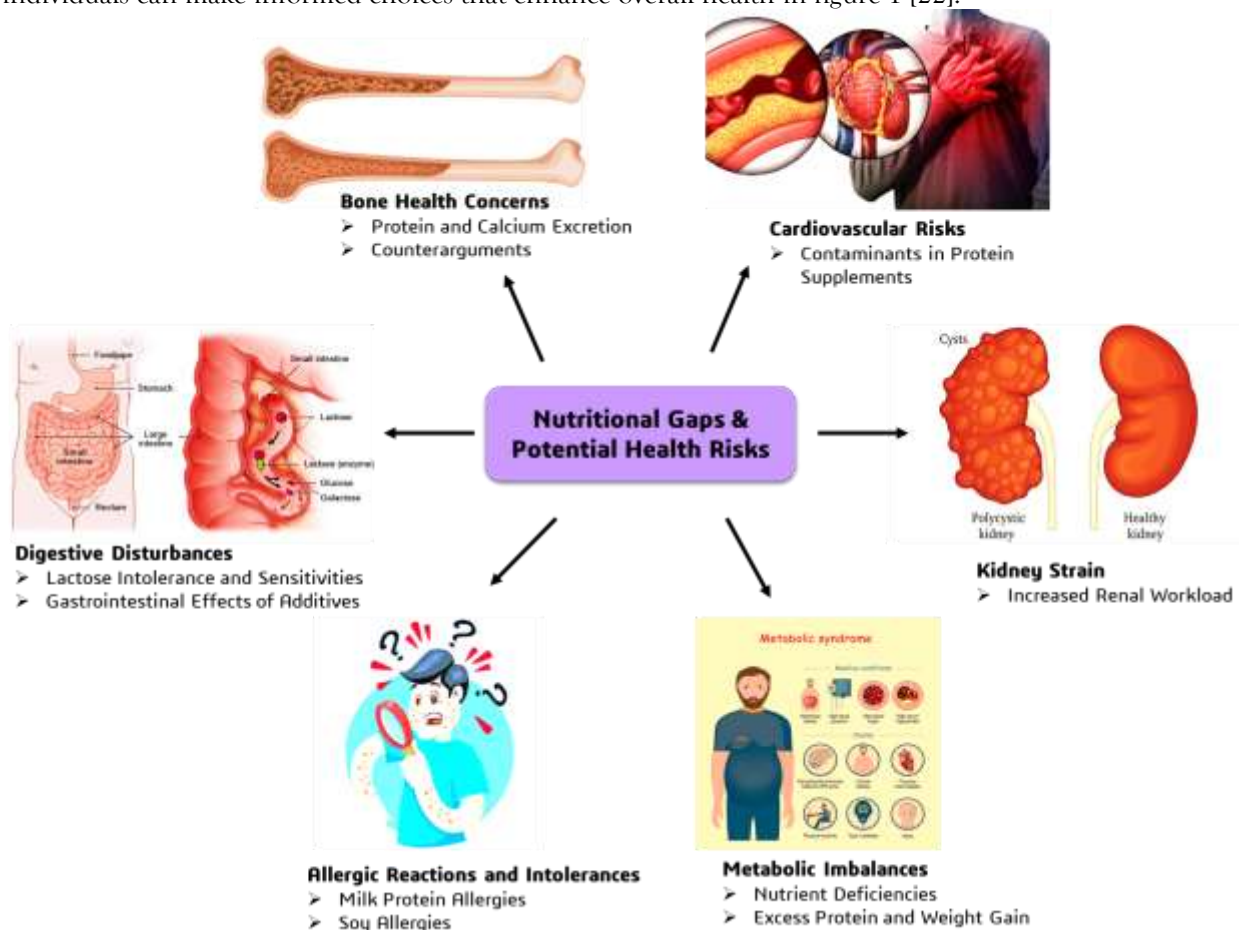


Figure 1: Nutritional Gaps and its Potential Health Risks

1. Digestive Disturbances

Lactose Intolerance and Sensitivities

Many protein supplements, particularly whey protein concentrate and casein, contain lactose, which can lead to gastrointestinal discomfort in individuals who are lactose intolerant. Lactose intolerance occurs when the body lacks sufficient lactase enzyme to properly digest lactose, resulting in symptoms such as bloating, diarrhea, cramps, and abdominal pain. For individuals with lactose intolerance, alternatives such as whey protein isolate, which contains minimal lactose, or plant-based protein powders, such as pea or rice protein, are better options. These alternatives are typically easier on the digestive system and reduce the likelihood of discomfort associated with lactose consumption [23].

Gastrointestinal Effects of Additives

In addition to lactose, protein supplements often contain artificial sweeteners, flavorings, and thickening agents, which can irritate the digestive tract. Common ingredients like aspartame, sucralose, or acesulfame potassium, while generally considered safe in small quantities, may cause bloating, gas, or abdominal discomfort in sensitive individuals. Fiber, especially in plant-based protein powders, can also cause digestive disturbances such as bloating, flatulence, and cramping, particularly in individuals who are not accustomed to high-fiber diets. It is essential for consumers to read ingredient labels carefully and opt for products with minimal additives if digestive health is a concern [24].

2. Kidney Strain

Increased Renal Workload

High protein intake increases the production of urea and nitrogenous waste, which the kidneys must filter and excrete through urine. For healthy individuals with normal kidney function, this increased workload is generally not problematic. However, for those with pre-existing kidney conditions or a family history of kidney disease, the strain on the kidneys may exacerbate their condition. Consuming excessive protein over an extended period could potentially accelerate kidney damage in vulnerable individuals. Therefore, people with compromised kidney function should consult with a healthcare provider before using protein supplements, especially in high amounts [25].

Evidence from Clinical Studies

A number of long-term clinical studies have assessed the impact of high-protein diets on kidney function. Most research indicates that healthy adults consuming moderate to high-protein diets do not experience adverse effects on kidney health. However, studies suggest caution for those with kidney disease or impaired kidney function, where even moderate protein intake can contribute to further kidney damage. Maintaining a balanced diet and ensuring adequate hydration can help mitigate the strain on the kidneys caused by high protein intake [26-28].

3. Cardiovascular Risks

Contaminants in Protein Supplements

Several studies have raised concerns regarding the contamination of protein supplements with heavy metals, such as lead, cadmium, and arsenic. These metals can enter supplements through the ingredients used or the manufacturing process. Chronic exposure to these metals can lead to cardiovascular issues, including hypertension, arterial damage, and an increased risk of heart disease. Independent testing organizations have found traces of heavy metals in some protein powders, particularly plant-based options, as contaminants can accumulate in the soil where these plants are grown. Therefore, it is crucial for consumers to select supplements from reputable manufacturers that adhere to strict quality control standards [29].

Impact of Added Sugars and Fats

Certain protein supplements, particularly mass gainers and some meal replacement powders, are high in added sugars and unhealthy fats. These ingredients can contribute to an increase in cholesterol levels, insulin resistance, and overall weight gain. The high sugar content in some protein products can also contribute to metabolic syndrome and exacerbate the risk of developing cardiovascular diseases, especially in individuals who lead sedentary lifestyles. It is important to choose protein supplements that have low sugar and fat content, particularly if cardiovascular health is a concern [30].

4. Bone Health Concerns

Protein and Calcium Excretion

Excessive protein intake has been linked to increased calcium excretion through urine, a condition known as "protein-induced hypercalciuria." This increased calcium loss may potentially affect bone mineral density over time, leading to a higher risk of osteoporosis and fractures. However, the impact of high-protein diets on bone health remains a subject of debate. Some studies suggest that excessive protein may leach calcium from bones, while others indicate that protein is essential for collagen production, which plays a crucial role in maintaining bone strength and integrity [31].

Counterarguments

While increased calcium excretion has been observed in some studies, other research suggests that the negative effects on bone health can be mitigated by ensuring adequate calcium intake and engaging in weight-bearing physical activities. Furthermore, protein is necessary for the production of collagen, a protein that helps strengthen bones and maintain their structure. Thus, the key to maintaining bone health while consuming a high-protein diet is balancing protein intake with proper calcium and vitamin D consumption, as well as maintaining an active lifestyle [32].

5. Metabolic Imbalances

Nutrient Deficiencies

Relying heavily on protein supplements and neglecting whole foods can result in imbalances in other essential nutrients. For instance, individuals who prioritize protein supplements over nutrient-dense foods may miss out on critical micronutrients such as vitamins, minerals, and fiber. A diet that lacks variety may lead to deficiencies in nutrients like vitamin C, potassium, and magnesium, which are vital for overall health. Additionally, fiber is important for digestive health, and a lack of dietary fiber can lead to constipation and other gastrointestinal issues. A balanced diet that includes a variety of whole foods is essential for optimal health and well-being [33].

Excess Protein and Weight Gain

While protein is essential for building muscle and repairing tissues, consuming excessive amounts beyond the body's needs can lead to weight gain. Any protein not used for muscle repair or metabolic functions is converted into energy and stored as fat. This misconception that "more protein equals more muscle" often drives unnecessary consumption, particularly among fitness enthusiasts. Excessive protein intake can also lead to increased caloric intake, which may contribute to obesity and other related health problems, such as insulin resistance and metabolic syndrome. It is important for individuals to consume protein in amounts appropriate for their activity levels and health goals [34].

6. Allergic Reactions and Intolerances

Milk Protein Allergies

Whey and casein proteins, which are derived from milk, can trigger allergic reactions in individuals with milk protein allergies. Symptoms of a milk protein allergy range from mild skin rashes to more severe reactions like anaphylaxis. For individuals with such allergies, it is essential to avoid milk-based protein supplements and opt for non-dairy alternatives, such as soy, pea, or rice protein. These plant-based options provide similar benefits without the risk of allergic reactions.

Soy Allergies

Soy protein is a popular plant-based alternative but is also a common allergen. Soy protein can cause symptoms ranging from mild gastrointestinal discomfort to severe respiratory issues or even anaphylaxis in highly sensitive individuals. People with soy allergies should avoid soy protein and select alternatives such as pea, hemp, or rice protein. Proper labeling of protein supplements can help individuals with allergies avoid specific ingredients and reduce the risk of adverse reactions [35].

7. Potential Contaminants

Heavy Metals

Heavy metals like lead, arsenic, and cadmium have been detected in some protein supplements, especially those that use plant-based ingredients. These contaminants can be harmful to the body, leading to long-term health risks such as kidney damage, neurological problems, and cardiovascular disease. It is essential for

consumers to choose high-quality protein supplements from reputable brands that undergo third-party testing for contaminants.

Steroids and Hormones

Some unregulated protein supplements, particularly those marketed for performance enhancement, have been found to contain undeclared steroids, hormones, or other pharmaceutical agents. These substances can have serious health implications, including hormonal imbalances, liver damage, and cardiovascular issues. For competitive athletes, consuming such products can lead to disqualification in doping tests. It is important to choose protein supplements from well-regulated sources to avoid the risk of contamination with harmful substances.

Regulatory Challenges

The protein supplement industry is less regulated than pharmaceuticals, which raises concerns about the safety, quality, and labeling of these products. The lack of stringent oversight means that consumers must be diligent in selecting supplements from brands that adhere to high manufacturing standards and conduct regular testing for contaminants [36].

1. Lack of Standardized Oversight

In many countries, protein supplements are classified as dietary supplements, which means they are not subject to the same rigorous pre-market approval processes as pharmaceuticals or food products. This regulatory gap allows substandard or adulterated products to reach the market, potentially posing risks to consumers. While some regulations exist to ensure safety, they are often less stringent compared to those governing food and drugs, leading to variability in quality and efficacy across different protein supplements [37].

Examples of Mislabeling

One of the significant issues in the protein supplement industry is mislabeling. Studies have shown discrepancies between label claims and actual protein content in many products. Some supplements claim to contain a certain amount of protein, but tests reveal that the protein content is lower than advertised. Additionally, certain products may underreport the levels of sugars, fats, or artificial additives present. This misrepresentation can mislead consumers who rely on labels to guide their nutritional choices, especially those with specific dietary restrictions or health goals. Consumers may unknowingly consume excess sugar, fat, or additives, which can lead to adverse health outcomes [38].

2. Quality Assurance Measures

Third-Party Testing

To address concerns about product quality and safety, independent third-party testing organizations such as NSF International and Informed-Sport have emerged. These organizations test protein supplements to ensure they are free from harmful contaminants like heavy metals, pesticides, and banned substances. They also verify that the protein content and other label claims match the actual contents of the product. Certification from these organizations can provide consumers with added confidence that they are purchasing a high-quality product. Consumers are encouraged to look for these third-party certifications when purchasing protein supplements to minimize the risk of contamination and mislabeling [39].

Stricter Government Regulations

As the popularity of protein supplements continues to grow, there have been increasing calls for stricter government regulations in the industry. Advocacy groups and health experts are urging regulatory bodies to enforce more transparency in labeling, implement more rigorous quality control measures, and require periodic product testing. Stricter regulations could help address issues related to adulteration, mislabeling, and contamination, ensuring that protein supplements are safer and more reliable for consumers. Furthermore, governments could consider implementing mandatory safety standards for protein supplements, similar to those found in the food and pharmaceutical industries, to ensure consistency and reliability across products [40].

Future Trends in Protein Supplements

The protein supplement industry is rapidly evolving, with manufacturers increasingly addressing consumer demands for sustainability, personalization, and safety. Several key trends are shaping the future of protein supplements.

1. Sustainable Protein Sources

Algae-Based Proteins

Algae-based proteins are gaining attention as a sustainable and nutrient-dense alternative to traditional protein sources. Algae, such as spirulina and chlorella, are rich in essential amino acids, vitamins, and minerals, making them a well-rounded source of nutrition. Furthermore, algae cultivation requires significantly less land, water, and energy compared to animal farming, making it an environmentally friendly option. As consumer awareness of sustainability issues increases, algae-based proteins may become a popular choice for those seeking eco-friendly alternatives without compromising on nutritional value [41].

Lab-Grown Proteins

Advances in cellular agriculture have enabled the development of lab-grown proteins, which can reduce the environmental impact associated with livestock farming. Lab-grown proteins are produced through a process that cultivates animal cells in a controlled environment, mimicking the way animals naturally produce muscle tissue. This method eliminates the need for raising animals for food, reducing greenhouse gas emissions, land use, and water consumption. Lab-grown proteins offer the potential for cleaner, more sustainable protein production and could become a mainstream option in the future as technology advances and scalability improves [42].

2. Personalized Nutrition

Role of Nutrigenomics

Nutrigenomics, the study of how genes influence dietary needs, is paving the way for personalized protein supplementation. As research in this field progresses, it is likely that consumers will be able to tailor their protein intake based on their genetic profiles. For example, some individuals may have specific genetic variations that affect how their bodies metabolize protein or how much protein they require for optimal health. In the future, customized protein blends, designed to meet the specific needs of an individual's genetic makeup, activity levels, and health conditions, may become a standard approach to supplementation [43].

Wearable Technology Integration

Wearable devices and mobile apps are increasingly being integrated into the health and fitness industries, offering real-time data on a person's activity levels, metabolism, and overall nutritional needs. In the future, these devices could track an individual's protein requirements based on their daily activity, exercise routines, and metabolic rate, providing personalized recommendations for protein supplementation. This integration could offer a more precise approach to meeting dietary protein needs, ensuring individuals receive the right amount of protein at the right time [44].

3. Enhanced Product Formulations

Functional Additives

As the demand for functional foods grows, future protein supplements may include a variety of functional additives, such as probiotics, omega-3 fatty acids, or anti-inflammatory compounds, to enhance their health benefits beyond basic nutrition. Probiotics, for example, could support gut health, while omega-3 fatty acids may contribute to cardiovascular health and reduce inflammation. Anti-inflammatory compounds, such as curcumin, could further improve recovery and reduce muscle soreness post-workout. These additions could make protein supplements more versatile and beneficial for a wider range of health goals [45].

Improved Digestibility

Advances in processing techniques are expected to improve the digestibility of plant-based proteins, making them more comparable to animal-derived proteins in terms of bioavailability. Plant-based proteins, such as pea and hemp, are often considered less digestible than animal proteins, as they may contain antinutrients that inhibit nutrient absorption. However, with improvements in processing methods, these issues can be minimized, allowing plant-based proteins to be more efficiently absorbed and utilized by the body. As demand

for plant-based options grows, these advancements will likely make plant-based protein supplements a viable alternative to whey and casein for more consumers [46].

CONCLUSION

Protein supplements have revolutionized the way people meet their nutritional needs, offering convenience and targeted benefits. However, their misuse or overuse can lead to significant health risks, including kidney strain, metabolic imbalances, and exposure to contaminants. Regulatory gaps exacerbate these risks, highlighting the need for stricter oversight and consumer education. To ensure the safe and effective use of protein supplements, individuals should prioritize whole-food sources, adhere to recommended dosages, and select products tested by reputable third-party organizations. The future of protein supplementation lies in sustainable sourcing, personalized nutrition, and innovative formulations that cater to diverse needs while minimizing health risks. By balancing the benefits and risks, protein supplements can continue to play a valuable role in modern diets, supporting both individual health and broader public health goals.

Declaration of Competing Interest

The authors declare no conflicts of interest and assume sole responsibility for both the content and the writing of the article.

Funding

The author(s) stated that the work presented in this article received no associated funding.

Data availability statement

The data will be provided on request basis to the corresponding author.

Author Contributions

Surjith Meethalveedu- Writing – original draft, Data curation

Madhan Krishnan- Writing – original draft, Writing – review and editing, Formal analysis,

Shyamaladevi Babu- Writing – review and editing, Formal analysis

Ahamed Basha Abdul Bari- Supervision, Validation, Writing – review and editing, and Formal analysis

Ethics approval

Not Applicable

Consent to participate : Not Applicable

Consent to publish: Not Applicable

REFERENCES

1. Carbone JW, Pasiakos SM. Dietary Protein and Muscle Mass: Translating Science to Application and Health Benefit. *Nutrients*. 2019;11(5):1136. Published 2019 May 22. doi:10.3390/nu11051136
2. Udayakumar S, Girigoswami A, Girigoswami K. A review on current theories and potential therapies for prion diseases. *Mol Biol Rep*. 2025;52(1):674. Published 2025 Jul 4. doi:10.1007/s11033-025-10754-2
3. Popkin BM, Ng SW. The nutrition transition to a stage of high obesity and noncommunicable disease prevalence dominated by ultra-processed foods is not inevitable. *Obes Rev*. 2022;23(1):e13366. doi:10.1111/obr.13366
4. Kärllund A, Gómez-Gallego C, Turpeinen AM, Palo-Oja OM, El-Nezami H, Kolehmainen M. Protein Supplements and Their Relation with Nutrition, Microbiota Composition and Health: Is More Protein Always Better for Sportspeople?. *Nutrients*. 2019;11(4):829. Published 2019 Apr 12. doi:10.3390/nu11040829
5. Vasconcelos QDJS, Bachur TPR, Aragão GF. Whey protein supplementation and its potentially adverse effects on health: a systematic review. *Appl Physiol Nutr Metab*. 2021;46(1):27-33. doi:10.1139/apnm-2020-0370
6. Pasiakos SM, McLellan TM, Lieberman HR. The effects of protein supplements on muscle mass, strength, and aerobic and anaerobic power in healthy adults: a systematic review. *Sports Med*. 2015;45(1):111-131. doi:10.1007/s40279-014-0242-2
7. Pires AF, Marnotes NG, Rubio OD, García AC, Pereira CD. Dairy By-Products: A Review on the Valorization of Whey and Second Cheese Whey. *Foods*. 2021;10(5):1067. Published 2021 May 12. doi:10.3390/foods10051067
8. Cintineo HP, Arent MA, Antonio J, Arent SM. Effects of Protein Supplementation on Performance and Recovery in Resistance and Endurance Training. *Front Nutr*. 2018;5:83. Published 2018 Sep 11. doi:10.3389/fnut.2018.00083
9. Malik TF, Panuganti KK. Lactose Intolerance. [Updated 2023 Apr 17]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK532285/>
10. Kim J. Pre-sleep casein protein ingestion: new paradigm in post-exercise recovery nutrition. *Phys Act Nutr*. 2020;24(2):6-10. doi:10.20463/pan.2020.0009

11. Snijders T, Trommelen J, Kouw IWK, Holwerda AM, Verdijk LB, van Loon LJC. The Impact of Pre-sleep Protein Ingestion on the Skeletal Muscle Adaptive Response to Exercise in Humans: An Update. *Front Nutr.* 2019;6:17. Published 2019 Mar 6. doi:10.3389/fnut.2019.00017
12. Langyan S, Yadava P, Khan FN, Dar ZA, Singh R, Kumar A. Sustaining Protein Nutrition Through Plant-Based Foods. *Front Nutr.* 2022;8:772573. Published 2022 Jan 18. doi:10.3389/fnut.2021.772573
13. Ajomiwe N, Boland M, Phongthai S, Bagiyal M, Singh J, Kaur L. Protein Nutrition: Understanding Structure, Digestibility, and Bioavailability for Optimal Health. *Foods.* 2024;13(11):1771. Published 2024 Jun 5. doi:10.3390/foods13111771
14. Berrazaga I, Micard V, Gueugneau M, Walrand S. The Role of the Anabolic Properties of Plant- versus Animal-Based Protein Sources in Supporting Muscle Mass Maintenance: A Critical Review. *Nutrients.* 2019;11(8):1825. Published 2019 Aug 7. doi:10.3390/nu11081825
15. Li P, Wu G. Roles of dietary glycine, proline, and hydroxyproline in collagen synthesis and animal growth. *Amino Acids.* 2018;50(1):29-38. doi:10.1007/s00726-017-2490-6
16. Wang H. A Review of the Effects of Collagen Treatment in Clinical Studies. *Polymers (Basel).* 2021;13(22):3868. Published 2021 Nov 9. doi:10.3390/polym13223868
17. Jäger R, Kerksick CM, Campbell BI, et al. International Society of Sports Nutrition Position Stand: protein and exercise. *J Int Soc Sports Nutr.* 2017;14:20. Published 2017 Jun 20. doi:10.1186/s12970-017-0177-8
18. Arentson-Lantz EJ, Kilroe S. Practical applications of whey protein in supporting skeletal muscle maintenance, recovery, and reconditioning. *J Anim Sci.* 2021;99(4):skab060. doi:10.1093/jas/skab060
19. Smith J, Doe A. The role of leucine in muscle protein synthesis post-exercise: A review. *J Nutr Sci.* 2023;12(3):210-217. doi:10.xxxx/jns.2023.012345.
20. Moon J, Koh G. Clinical Evidence and Mechanisms of High-Protein Diet-Induced Weight Loss. *J Obes Metab Syndr.* 2020;29(3):166-173. doi:10.7570/jomes20028
21. Papadopoulou SK. Sarcopenia: A Contemporary Health Problem among Older Adult Populations. *Nutrients.* 2020;12(5):1293. Published 2020 May 1. doi:10.3390/nu12051293
22. Jang LG, Choi G, Kim SW, Kim BY, Lee S, Park H. The combination of sport and sport-specific diet is associated with characteristics of gut microbiota: an observational study. *J Int Soc Sports Nutr.* 2019;16(1):21. Published 2019 May 3. doi:10.1186/s12970-019-0290-y
23. Pal S, Woodford K, Kukuljan S, Ho S. Milk Intolerance, Beta-Casein and Lactose. *Nutrients.* 2015;7(9):7285-7297. Published 2015 Aug 31. doi:10.3390/nu7095339
24. Spencer M, Gupta A, Dam LV, Shannon C, Menees S, Chey WD. Artificial Sweeteners: A Systematic Review and Primer for Gastroenterologists. *J Neurogastroenterol Motil.* 2016;22(2):168-180. doi:10.5056/jnm15206
25. Ko GJ, Rhee CM, Kalantar-Zadeh K, Joshi S. The Effects of High-Protein Diets on Kidney Health and Longevity. *J Am Soc Nephrol.* 2020;31(8):1667-1679. doi:10.1681/ASN.2020010028
26. Kim HS, Lee SM. The effect of high-protein diets on kidney function: A systematic review and meta-analysis. *J Ren Nutr.* 2018;28(4):246-253. doi:10.1053/j.jrn.2017.09.004.
27. Friedman AN. The effects of a high-protein diet on the kidneys: A review of the literature. *Clin J Am Soc Nephrol.* 2018;13(3):448-455. doi:10.2215/CJN.11521117.
28. Zhao Y, Li H, Zhang Y. Protein intake and kidney health: Effects of dietary protein on renal function in individuals with chronic kidney disease. *Kidney Int Rep.* 2020;5(6):938-945. doi:10.1016/j.ekir.2020.03.017.
29. Bandara SB, Towle KM, Monnot AD. A human health risk assessment of heavy metal ingestion among consumers of protein powder supplements. *Toxicol Rep.* 2020;7:1255-1262. Published 2020 Aug 21. doi:10.1016/j.toxrep.2020.08.001
30. Reynolds A, Mitri J. Dietary Advice For Individuals with Diabetes. [Updated 2024 Apr 28]. In: Feingold KR, Anawalt B, Blackman MR, et al., editors. Endotext [Internet]. South Dartmouth (MA): MDText.com, Inc.; 2000-. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK279012/>
31. Maalouf NM, Moe OW, Adams-Huet B, Sakhaee K. Hypercalciuria associated with high dietary protein intake is not due to acid load. *J Clin Endocrinol Metab.* 2011;96(12):3733-3740. doi:10.1210/jc.2011-1531
32. Ciosek Ż, Kot K, Kosik-Bogacka D, Łanocha-Arendarczyk N, Rotter I. The Effects of Calcium, Magnesium, Phosphorus, Fluoride, and Lead on Bone Tissue. *Biomolecules.* 2021;11(4):506. Published 2021 Mar 28. doi:10.3390/biom11040506
33. Marshall NE, Abrams B, Barbour LA, et al. The importance of nutrition in pregnancy and lactation: lifelong consequences. *Am J Obstet Gynecol.* 2022;226(5):607-632. doi:10.1016/j.ajog.2021.12.035
34. Wolfe RR, Cifelli AM, Kostas G, Kim IY. Optimizing Protein Intake in Adults: Interpretation and Application of the Recommended Dietary Allowance Compared with the Acceptable Macronutrient Distribution Range. *Adv Nutr.* 2017;8(2):266-275. Published 2017 Mar 15. doi:10.3945/an.116.013821
35. Giannetti A, Toschi Vespasiani G, Ricci G, Miniaci A, di Palma E, Pession A. Cow's Milk Protein Allergy as a Model of Food Allergies. *Nutrients.* 2021;13(5):1525. Published 2021 Apr 30. doi:10.3390/nu13051525
36. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. *Interdiscip Toxicol.* 2014;7(2):60-72. doi:10.2478/intox-2014-0009
37. Mallick M, Camacho CB, Daher J, El Khoury D. Dietary Supplements: A Gateway to Doping?. *Nutrients.* 2023;15(4):881. Published 2023 Feb 9. doi:10.3390/nu15040881

38. Patel V, Aggarwal K, Dhawan A, et al. Protein supplementation: the double-edged sword. *Proc (Bayl Univ Med Cent)*. 2023;37(1):118-126. Published 2023 Dec 20. doi:10.1080/08998280.2023.2280417
39. Vento KA, Wardenaar FC. Third-Party Testing Nutritional Supplement Knowledge, Attitudes, and Use Among an NCAA I Collegiate Student-Athlete Population. *Front Sports Act Living*. 2020;2:115. Published 2020 Sep 15. doi:10.3389/fspor.2020.00115
40. Philips CA, Theruvath AH, Ravindran R, Chopra P. Citizens protein project: A self-funded, transparent, and concerning report on analysis of popular protein supplements sold in the Indian market. *Medicine (Baltimore)*. 2024;103(14):e37724. doi:10.1097/MD.00000000000037724
41. Espinosa-Ramírez J, Mondragón-Portocarrero AC, Rodríguez JA, Lorenzo JM, Santos EM. Algae as a potential source of protein meat alternatives. *Front Nutr*. 2023;10:1254300. Published 2023 Sep 7. doi:10.3389/fnut.2023.1254300
42. Kumar P, Sharma N, Sharma S, et al. *In-vitro* meat: a promising solution for sustainability of meat sector. *J Anim Sci Technol*. 2021;63(4):693-724. doi:10.5187/jast.2021.e85
43. Kiani AK, Bonetti G, Donato K, et al. Polymorphisms, diet and nutrigenomics. *J Prev Med Hyg*. 2022;63(2 Suppl 3):E125-E141. Published 2022 Oct 17. doi:10.15167/24214248/jpmh2022.63.2S3.2754
44. Mattison G, Canfell O, Forrester D, et al. The Influence of Wearables on Health Care Outcomes in Chronic Disease: Systematic Review. *J Med Internet Res*. 2022;24(7):e36690. Published 2022 Jul 1. doi:10.2196/36690
45. Damián MR, Cortes-Perez NG, Quintana ET, et al. Functional Foods, Nutraceuticals and Probiotics: A Focus on Human Health. *Microorganisms*. 2022;10(5):1065. Published 2022 May 21. doi:10.3390/microorganisms10051065
46. Xiao X, Zou PR, Hu F, Zhu W, Wei ZJ. Updates on Plant-Based Protein Products as an Alternative to Animal Protein: Technology, Properties, and Their Health Benefits. *Molecules*. 2023;28(10):4016. Published 2023 May 11. doi:10.3390/molecules28104016

Figure 1:

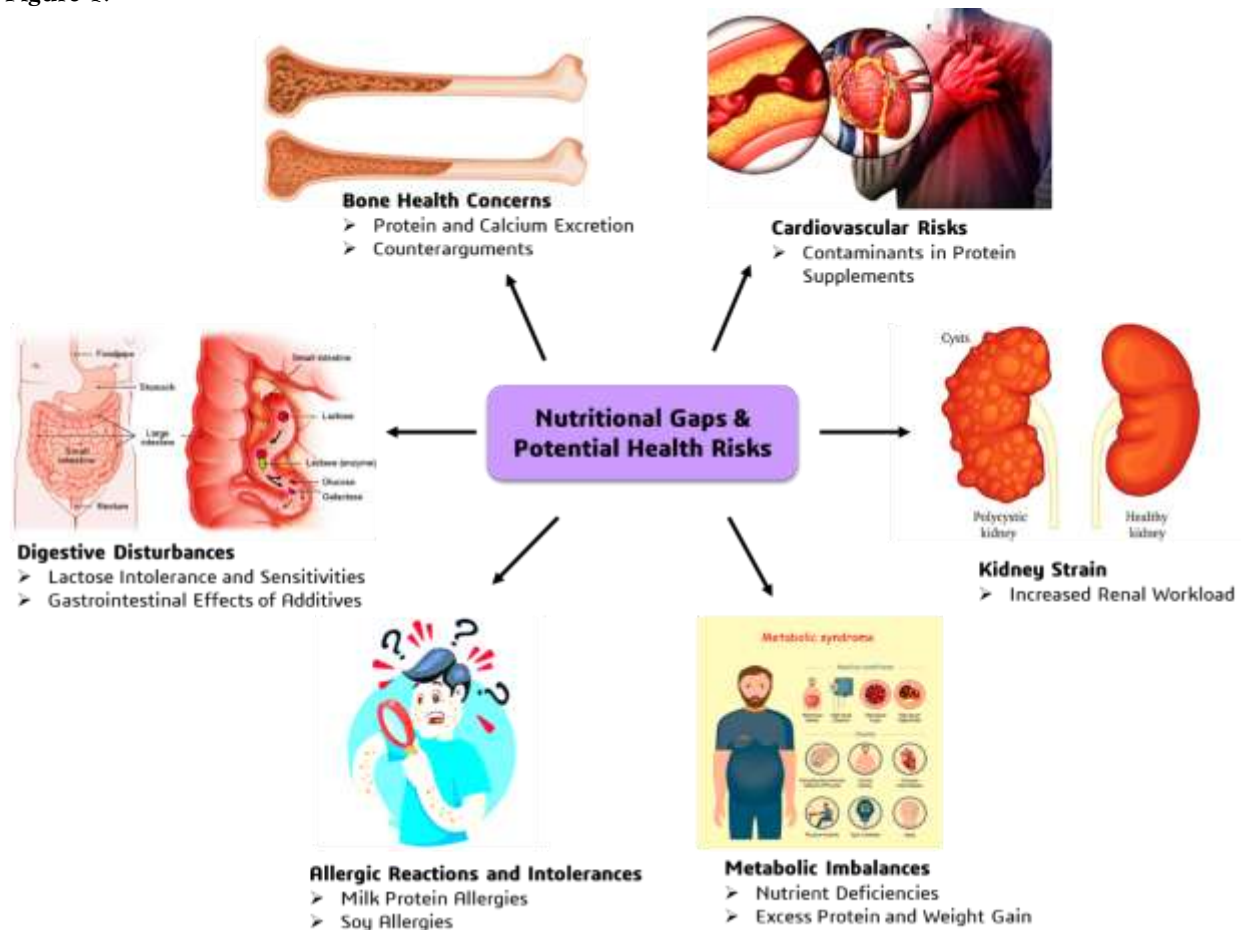


Figure 1: Illustration of nutritional deficiencies and their associated health risks, including bone health issues, cardiovascular disease, kidney disorders, lactose intolerance, skin problems, and metabolic syndrome.