The Pharma Innovation Journal 2023; 12(7): 3424-3434

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(7): 3424-3434

www.thepharmajournal.com
Received: 03-05-2023
Accepted: 14-06-2023

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Chickpea protein: A comprehensive review on nutritional properties, processing, functionality, applications, and sustainable impact

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Abstract
Chickpea protein has emerged as a promising and versatile ingredient in the food industry, playing a pivotal role in formulating meat analogs and a wide range of plant-based products. As global concerns regarding the environmental and health impacts of animal-based protein consumption continue to rise, the demand for sustainable and nutritious plant-based alternatives has escalated. Chickpea protein, derived from the leguminous crop *Cicer arietinum*, offers a compelling solution to meet these evolving consumer preferences. This review paper provides a comprehensive and up-to-date overview of chickpea protein and its significance in human nutrition and the food industry. It delves into the nutritional properties of chickpea protein, highlighting its high protein content, complete amino acid profile, and rich source of essential nutrients. The protein content in chickpeas ranges from 19% to 25%, making them one of the highest-protein legumes available. The review explores traditional and modern methods of chickpea protein extraction, including milling and sieving, water extraction, acid extraction, alkaline extraction, enzyme-assisted extraction, and ultrafiltration. Each extraction technique is evaluated in terms of efficiency and effectiveness, offering insights into the advancements and challenges in protein isolation. Chickpea protein's functional properties, such as its ability to form gels, provide texture, and emulsify fats and water, make it an excellent ingredient for creating meat analogs with meat-like texture and mouthfeel. Additionally, its emulsifying and binding capabilities allow for the formulation of cohesive and satisfying plant-based products. The protein's versatility enables its use in various forms, such as isolates, concentrates, and textured proteins, contributing to the development of a diverse array of plant-based foods, including dairy alternatives, snacks, frozen desserts, nutritional supplements, and gluten-free products. Furthermore, this paper highlights the nutritional and health benefits of chickpea protein, including its role as a complete protein, supporting muscle growth and repair. Chickpea protein's impact on heart health, blood sugar management, weight management, digestive health, antioxidant properties, and bone health are discussed, showcasing its potential role in promoting overall well-being.

Keywords: Chickpea protein, nutritional properties, sustainable impact

1. Introduction

In recent years, the environmental and health implications of animal-based protein consumption have gained increasing attention worldwide. The intensive livestock farming practices associated with animal protein production have been linked to a range of environmental issues, including greenhouse gas emissions, deforestation, and water pollution (Henchion *et al*., 2021) [31]. Moreover, excessive consumption of certain animal proteins has been connected to health problems such as cardiovascular diseases and obesity (Deledda *et al*., 2021) [19]. These concerns have spurred a global movement towards adopting more sustainable and plant-based diets, with plant proteins becoming a focal point in this shift (Lonnie & Johnstone, 2020) [47].

One of the standout contenders in the realm of plant-based proteins is chickpea protein, derived from the leguminous crop known as *Cicer arietinum* (Israel *et al*., 2022) [34]. Chickpeas boast a long history of cultivation, dating back thousands of years, and have become a dietary staple in numerous cultures across the globe (Chapman *et al*., 2022) [16]. Beyond their carbohydrate and dietary fiber content, chickpeas are highly regarded for their exceptional quality as a plant-based protein source. The protein content in chickpeas typically ranges from 19% to 25%, positioning them as one of the highest-protein legumes available (Lappi *et al*., 2022) [46].

The importance of chickpea protein goes beyond its nutritional benefits. One of its key advantages lies in its contribution to environmental sustainability (Saget *et al*., 2020) [70].

Chickpea plants possess a unique ability to fix nitrogen from the atmosphere, forming a symbiotic relationship with specific bacteria that convert nitrogen gas into a usable form for the plant (Raza *et al*., 2020) [67]. This natural nitrogen fixation process significantly reduces the need for synthetic nitrogen fertilizers in chickpea cultivation, lessening the environmental impact associated with fertilizer production and usage. As a result, chickpea cultivation contributes to reduced greenhouse gas emissions and helps mitigate the effects of climate change (Soumare *et al*., 2020) [74].

Furthermore, chickpeas exhibit remarkable resilience to drought conditions compared to other major crops, making them well-suited for cultivation in regions facing water scarcity (Phiri *et al*., 2023) [63]. Their ability to adapt to diverse climatic conditions and flourish in nutrient-poor soils further enhances their value in sustainable food production systems (Sokolow *et al*., 2019) [73].

Chickpea protein has garnered substantial interest within the food industry as a versatile and nutritious ingredient. Its functional properties make it an excellent candidate for various food applications (Nasrabadi *et al*., 2021) [61]. For instance, chickpea protein's emulsifying and foaming capabilities enable it to stabilize and improve the texture of food products, while its gelation and water-holding capacities contribute to the formulation of meat analogs, bakery items, and protein supplements (Ma *et al*., 2022) [48]. The versatility of chickpea protein in various food formulations supports the development of plant-based alternatives to traditional animal-based products, catering to the increasing demand for sustainable and healthier food choices (Singh *et al*., 2021) [72].

In conclusion, the rising awareness of the environmental and health impacts of animal-based proteins has led to a global shift towards more sustainable and plant-based diets (Espinosa-Marrón *et al*., 2022) [20]. Chickpea protein has emerged as a promising and sustainable alternative, offering a nutritious and versatile option for the food industry. With its potential to address both nutritional and environmental challenges, chickpea protein stands as a pivotal player in the quest for a more sustainable and health-conscious food system (Affrifah *et al*., 2023) [1]. As research and innovation continue to explore the full potential of chickpea protein, it is expected to play an even more significant role in shaping the future of sustainable food production and consumption (Ismail *et al*., 2020) [33].

The primary objective of this review paper is to provide a comprehensive overview of chickpea protein's significance in human nutrition and the food industry. It aims to cover various aspects, including its nutritional composition, amino acid profile, and protein quality compared to other sources. The review will explore traditional and modern processing methods for chickpea protein extraction. Additionally, it will delve into its functional properties, making it suitable for diverse food applications. The paper will highlight chickpea protein's versatility in developing meat analogs, plant-based products, and protein supplements, fostering sustainable food systems by discussing its role in crop rotation and soil health improvement.

2. Chickpea (*Cicer arietinum*)

2.1 Botanical Description and Taxonomy

Chickpea (*Cicer arietinum*) is a member of the legume family (Fabaceae) and is widely cultivated for its edible seeds (Mangena, 2020) [50]. It is an annual herbaceous plant with a deep taproot system, allowing it to access water and nutrients from deeper soil layers. The plant typically grows to a height of 20 to 50 centimeters, although it can vary depending on the variety and growing conditions (Zhou *et al*., 2020) [85]. The leaves of chickpeas are compound, consisting of three leaflets, and are arranged alternately along the stem. The flowers are white, pink, or purple and are borne in clusters (Jukanti *et al*., 2019) [38]. Chickpeas is a self-pollinating plant, but cross-pollination can also occur in some cases. The fruit of chickpeas is a pod containing one to two seeds, commonly known as chickpeas or garbanzo beans (Chand *et al*., 2021) [14]. The seeds are usually round, smooth-textured, and come in various colors, including beige, green, black, and red, depending on the variety (Majid *et al*., 2020) [49].

2.2 Historical and Geographical Distribution

Chickpeas have a long history of cultivation and consumption, dating back to ancient times (Piergiovanni, 2021) [64]. They are believed to have originated in the Middle East and the Mediterranean region, where archaeological evidence indicates their presence as early as 7,500 years ago. From these regions, chickpeas spread to other parts of the world through trade and exploration (Aizpurua-Iraola *et al*., 2023) [3].

Today, chickpeas are cultivated in many countries across different continents. Major producing countries include India, Pakistan, Turkey, Ethiopia, and Mexico (Yegrem, 2021) [83]. Chickpeas are grown in a wide range of climates, from temperate to subtropical and tropical regions, making them versatile crops with adaptability to diverse environmental conditions (Mayes *et al*., 2019) [53].

2.3 Nutritional Value of Chickpea

Chickpeas, with their exceptional nutritional profile, is a prized addition to a balanced diet. They offer a rich source of macronutrients, micronutrients, and dietary fiber, making them a valuable food choice for maintaining overall health and wellness (Sharoba, 2014) [71]. The protein content of chickpeas, averaging between 19% to 25% by weight, is particularly noteworthy (Lago-Olveira *et al*., 2023) [42]. This protein is considered of excellent quality as it contains all essential amino acids required by the human body. While some amino acids, such as methionine, may be present in slightly lower levels compared to animal-based proteins, chickpea protein can still play an essential role in a well-rounded plant-based diet. Chickpeas also provide a substantial amount of complex carbohydrates, mainly in the form of starch. These carbohydrates serve as a sustained source of energy and help regulate blood sugar levels, making them an excellent option for maintaining stable energy levels throughout the day (Aizpurua-Iraola *et al*., 2023) [3]. An outstanding feature of chickpeas is their high dietary fiber content. Dietary fiber plays a crucial role in promoting digestive health by supporting regular bowel movements and reducing the risk of constipation (Maphosa & Jideani, 2017) [52]. Additionally, the fiber in chickpeas contributes to a feeling of fullness, which can aid in weight management and help control appetite. The fat content of chickpeas is relatively low, and the majority of the fats are unsaturated fats, considered heart-healthy fats that support cardiovascular health (Jukanti *et al*., 2012) [37]. Chickpeas are also rich in essential vitamins, including folate (vitamin B9), which is particularly important for pregnant women as it supports fetal development (Mironenko & Eliseeva, 2019) [56]. Additionally, chickpeas provide vitamins C, E, and K, which contribute to overall health and immune function. Regarding minerals, chickpeas offer a valuable source of iron, magnesium, potassium, phosphorus, and zinc (Mohamed *et al*., 2020) [58]. Iron is crucial for transporting oxygen in the blood, magnesium and potassium play roles in maintaining healthy blood pressure and muscle function, while phosphorus and zinc support various physiological processes in the body (Jomova *et al*., 2022) [35]. Moreover, chickpeas contain a range of antioxidants, such as flavonoids and polyphenols, which help protect the body from oxidative stress and inflammation. These antioxidants contribute to various health benefits and are essential for overall well-being. Numerous studies have further emphasized the nutritional significance of consuming chickpeas (Brodowska, 2017) [13]. Research has shown that different chickpea varieties may vary in protein content and amino acid profiles, reinforcing the importance of considering chickpea diversity when evaluating its nutritional value. Studies have also highlighted that chickpeas' high protein content and well-balanced amino acid profile make them suitable for various food formulations and fortification programs (Rehman *et al*., 2019) [68]. The antioxidant potential of chickpeas has been emphasized, showcasing their role in reducing oxidative stress and inflammation, contributing to various health benefits (Wang *et al*., 2011) [78]. Incorporating chickpeas into one's diet can be a beneficial step towards improved health and wellness. Whether as a protein source, a fiber-rich addition to meals, or a nutrient-dense ingredient, chickpeas offer a versatile and nourishing option as part of a balanced and varied plant-based diet (Bessada *et al*., 2019) [7].

3. Protein Composition of Chickpea

3.1 Major Protein Fractions

Chickpea protein consists of several distinct protein fractions, each with unique functional and nutritional properties. These major protein fractions, namely albumins, globulins, prolamins, and glutelins, collectively contribute to the overall nutritional profile and versatility of chickpea protein in various food applications (Grossmann, 2023) [28]. Albumins, which make up a significant portion of chickpea protein, are water-soluble proteins. They play crucial roles within the plant, facilitating nutrient transport and storage (J. Boye *et al*., 2010) [10]. Due to their small size and solubility in water and weak acid solutions, albumins are easily digestible and can be readily utilized by the human body. Globulins form another major fraction of chickpea protein. These proteins are soluble in dilute salt solutions and are characterized by their globular shape (Pimenta *et al*., 2023) [65]. Globulins play essential roles in enzyme regulation and support the proper functioning of the immune system. Their well-balanced amino acid composition adds to their nutritional value, making them valuable components of a healthy diet. Prolamins, on the other hand, are alcohol-soluble proteins found in chickpeas (Ahmed *et al*., 2022) [2]. They are primarily responsible for storing amino acids and nitrogen within the seed. However, prolamins are relatively resistant to proteolytic enzymes, which can affect their digestibility to some extent. Finally, glutelins make up an insoluble fraction of chickpea protein, being neither soluble in water nor alcohol (Bera *et al*., 2023) [6]. These proteins play a crucial role in maintaining the cohesive structure of chickpea seeds, forming the protein matrix within the seed. Rich in glutamine and proline, glutelins contribute to the unique properties of chickpea protein (Bessada *et al*., 2019) [7]. The presence of these diverse protein fractions in chickpea protein makes it a valuable ingredient in various food applications. Chickpea protein's solubility and digestibility are influenced by the different protein fractions, impacting its functionality in food formulations (Mookerjee & Tanaka, 2022) [59]. For instance, albumins and globulins are often exploited for their emulsification and foaming properties, making chickpea protein a suitable plant-based alternative in various food products. Furthermore, the balanced amino acid composition of chickpea protein enhances its nutritional quality, particularly when combined with other plant-based protein sources to form complementary protein profiles (Vogelsang *et al*., 2021) [77]. The diverse protein fractions also contribute to chickpea protein's ability to gel and bind water, which is useful in the development of meat analogs, plant-based burgers, and other structured food products. In conclusion, chickpea protein's composition of albumins, globulins, prolamins, and glutelins offers unique functional and nutritional attributes, making it a valuable and versatile ingredient in the food industry (Webb *et al*., 2023) [79]. Whether used as a primary protein source or in combination with other plant-based proteins, chickpea protein provides a sustainable and nutrient-rich option for meeting the demands of the growing plant-based food market (Maningat *et al*., 2022) [51].

3.2 Amino Acid Profile

The amino acid profile of chickpea protein is one of its key strengths. Chickpeas contain all essential amino acids, making them a complete protein source for human nutrition. Essential amino acids are those that the human body cannot synthesize and must be obtained from the diet. However, chickpea protein does have some limitations in certain amino acids. Methionine and cysteine, sulfur-containing amino acids, are present in relatively lower levels in chickpeas compared to animal-based proteins. On the other hand, chickpea protein is relatively higher in lysine compared to some other plant-based proteins like cereals (Grasso *et al*., 2022) [27].

To overcome the amino acid limitations of chickpea protein, it is often recommended to combine it with other plant-based protein sources, such as grains, to create a complementary protein profile. This can be achieved through traditional food pairings like chickpeas and rice, which together provide a more balanced amino acid profile.

3.3 Protein Digestibility and Bioavailability

Protein digestibility is a critical aspect of evaluating the nutritional value of chickpea protein. The digestibility of a protein refers to the proportion of amino acids absorbed and utilized by the human body after consumption. Chickpea protein has shown to have good digestibility; however, it may be slightly lower compared to animal-based proteins (J. Boye *et al*., 2012) [8]. One factor influencing the digestibility of chickpea protein is the presence of anti-nutritional factors, such as protease inhibitors and phytates, which can hinder protein breakdown during digestion. To enhance the digestibility of chickpea protein, various processing methods can be employed. Studies have demonstrated that heat treatment, such as cooking and roasting, can reduce the levels of anti-nutritional factors, improving protein digestibility (Xu *et al*., 2016) [82]. Bioavailability, on the other hand, refers to the extent to which the absorbed amino acids are utilized by the body for various physiological functions. Chickpea protein has been found to have good bioavailability, and its amino acids are effectively incorporated into body tissues and proteins (J. Boye *et al.*, 2012) [8].

In conclusion, chickpea protein contains several major protein fractions, each with unique properties contributing to its nutritional and functional characteristics. The amino acid profile of chickpea protein is well-balanced, although it may have slightly lower levels of certain amino acids compared to animal proteins. Chickpea protein has good digestibility and bioavailability, and its nutritional quality can be optimized through proper processing and dietary combinations, making it an excellent choice for meeting protein needs in plant-based diets.

4. Processing and Extraction of Chickpea Protein

4.1 Traditional Processing Methods

Traditional methods for extracting chickpea protein have been practiced for centuries in different cultures around the world. These methods are relatively straightforward and rely on conventional techniques to isolate protein from chickpea seeds. Here is a detailed explanation of each traditional processing method.

4.1.1 Milling and Sieving

The first step in this method is to mill the chickpea seeds into a fine flour-like consistency. The milling process breaks down the seeds into smaller particles, increasing the surface area and facilitating subsequent protein extraction. The milled chickpea flour contains protein, starch, fiber, and other components of the seed (Farooq & Boye, 2011) [22]. After milling, the chickpea flour is then sieved to separate the protein-rich fraction from the other components. Sieving involves passing the flour through a mesh or sieve that separates the particles based on size. The protein-rich fraction, which consists of smaller particles, passes through the sieve, while the larger particles of starch and fiber are retained (Thakur *et al.*, 2019) [75]. This process can be repeated multiple times to enhance the purity of the protein-rich fraction. By sieving the chickpea flour multiple times, the protein content can be concentrated, and unwanted components can be removed, resulting in a higher concentration of protein (Xu *et al.*, 2016) [82].

4.1.2 Water Extraction

In the water extraction method, chickpea flour is soaked in water to extract the soluble proteins. The mixture is agitated or stirred to facilitate the release of proteins from the chickpea flour into the water. As proteins are water-soluble, they dissolve in the water during the extraction process (Xiao *et al.*, 2015) [80]. After the protein extraction, the mixture is allowed to settle, and the liquid fraction, which contains the extracted proteins, is separated from the insoluble components of the chickpea flour. The separation can be achieved by decantation or centrifugation, where the liquid is carefully poured off or spun at high speeds, respectively, to separate the protein-rich liquid from the solids (J. I. Boye & Barbana, 2012) [8].

4.1.3 Acid Extraction

The acid extraction method involves mixing chickpea flour with a weak acid solution. The acid helps to solubilize the proteins, breaking down protein-protein interactions and facilitating their release from the chickpea flour. After mixing with the acid, the mixture is subjected to subsequent filtration or centrifugation (Lam *et al.*, 2018) [44]. These separation techniques are used to isolate the protein-rich extract from the insoluble components of the chickpea flour. The protein-rich extract contains solubilized proteins, which are now separated from other constituents. It is important to note that traditional processing methods, while effective in extracting chickpea protein, may have some limitations. These methods may not yield as high a protein purity as modern extraction techniques, and they may not be as efficient in removing certain anti-nutritional factors. However, they have been used for generations and remain valuable in small-scale and traditional food processing contexts. In contrast, modern extraction techniques, as discussed earlier, utilize advanced technology to achieve higher protein yields and purity, making them suitable for large-scale industrial applications and addressing some of the limitations of traditional methods.

4.2 Modern Extraction Techniques

Modern extraction techniques for chickpea protein have evolved with technological advancements, allowing for more efficient and controlled protein isolation. These methods leverage various principles to achieve higher protein yields and purity. Here is a detailed explanation of each modern extraction technique.

4.2.1 Alkaline Extraction

In alkaline extraction, chickpea flour is treated with an alkaline solution, typically using sodium hydroxide (NaOH) or potassium hydroxide (KOH). The alkaline solution helps to increase the pH of the mixture, creating a more basic environment. This change in pH causes the proteins to undergo conformational changes, leading to their solubilization. The solubilized proteins are separated from other components, such as starch and fiber, using filtration or centrifugation. The recovered protein-rich extract can be further processed to adjust the alkalinity to optimize protein functionality for specific applications. Alkaline extraction has proven to be an effective method for isolating chickpea protein, as it provides high yields and improved protein purity. The solubility of proteins in alkaline conditions allows for easy separation from the insoluble components of chickpea flour.

4.2.2 Enzyme-Assisted Extraction

Enzyme-assisted extraction involves the use of specific proteolytic enzymes to break down protein-protein interactions within the chickpea flour. The addition of proteases, such as papain and bromelain, helps to selectively hydrolyze protein fractions, releasing them from the complex protein matrix. The hydrolyzed proteins are then separated from the non-hydrolyzed components using filtration or centrifugation. The resulting protein-rich extract contains hydrolyzed proteins, which have improved functionality and solubility compared to the intact proteins in the flour. Enzyme-assisted extraction is particularly beneficial for increasing protein yields and improving protein functionality. By selectively breaking down protein bonds, the proteases enhance the solubility and dispersibility of the proteins, making them more suitable for various food applications.

4.2.3 Ultrafiltration
Ultrafiltration is a membrane-based separation technique that relies on the size exclusion principle. The chickpea protein extract is passed through a semipermeable membrane with specific pore sizes. The membrane acts as a filter, allowing smaller molecules, such as water and small solutes, to pass through while retaining larger molecules, including proteins. By using membranes with specific pore sizes, the larger protein molecules are concentrated in the retentate, while the smaller molecules are collected in the permeate. This process allows for the concentration of protein and the removal of unwanted components, such as anti-nutritional factors. Ultrafiltration is advantageous for improving the purity and concentration of chickpea protein. By selectively retaining protein molecules based on their size, ultrafiltration can effectively separate protein fractions, leading to higher protein content in the final extract.

In conclusion, modern extraction techniques for chickpea protein, such as alkaline extraction, enzyme-assisted extraction, and ultrafiltration, have significantly advanced protein isolation processes. These methods offer higher yields, improved purity, and enhanced protein functionality compared to traditional processing methods. The use of advanced technology and principles in these extraction techniques contributes to the optimization of chickpea protein for various food applications, making it a valuable and sustainable protein source in the food industry.

Table 1: Extraction techniques of chickpea protein

Method name	Protein yield %	Advantages	Disadvantages	References
wet milling	49.36	High protein purity, high-fat absorption capacity, low-fat content, high starch granule integrity, and light color	Loss of protein fractions, energy and water consuming process, low water holding capacity, less foaming stabilizability	(Espinosa-Ramírez & Serna-Saldívar, 2019) [21]
Dry fraction	11-31	Sustainable process, no additives, minimum processing, deliver functional protein fraction and intact structure	Low purity of protein, presence of anti-nutritional factors (phytic acid, tannins, trypsin inhibitor, α - galactosides), and low foaming capacity	(Xing *et al.*, 2021) [81]
Alkaline extraction	67-68	High-yield protein and high protein purity	Consumption of high amounts of water and energy, loss of native functionality, improve functional properties	(Moczkowska *et al.*, 2019) [57]
Wet extraction	58	High yield protein, high purity, stabilize the emulsion	Water-consuming process, low solubility	(Lakshmikandan *et al.*, 2020) [43]

4.3 Challenges and Advancements in Extraction
Challenges in chickpea protein extraction include obtaining high protein yields while maintaining protein functionality and minimizing the presence of anti-nutritional factors. Some proteins are sensitive to heat, pH, and shear forces during extraction, which can lead to protein denaturation and reduced functionality. Additionally, the presence of anti-nutritional factors, such as trypsin inhibitors and phytates, can hinder protein digestibility and bioavailability. Advancements in extraction techniques have addressed some of these challenges. Enzyme-assisted extraction has shown promise in improving protein yields while maintaining protein functionality. Studies have demonstrated that the use of specific proteolytic enzymes can increase protein extraction efficiency and reduce the presence of anti-nutritional factors. Ultrafiltration has also emerged as an efficient method to concentrate protein and remove unwanted compounds. Research has shown that ultrafiltration can significantly increase protein purity and reduce the levels of anti-nutritional factors. Moreover, advances in processing equipment and technology have led to more precise control over extraction parameters, allowing for optimized protein extraction conditions. This has resulted in improved protein yields and better preservation of protein functionality (Freitas *et al.*, 2005) [23].

In conclusion, chickpea protein extraction has evolved from traditional methods to more sophisticated and efficient techniques. Modern extraction methods, such as alkaline extraction, enzyme-assisted extraction, and ultrafiltration, offer higher protein yields and improved protein purity while addressing challenges related to protein functionality and the presence of anti-nutritional factors. These advancements are critical in harnessing the full potential of chickpea protein as a sustainable and nutritious ingredient for various food applications.

5. Functional and Technological Properties of Chickpea Protein
5.1 Emulsifying and Foaming Properties
Chickpea protein exhibits excellent emulsifying and foaming properties, making it a valuable ingredient in various food formulations. Emulsification is the process of dispersing one liquid phase into another, typically oil into water, creating a stable and homogeneous mixture. Foaming, on the other hand, involves the incorporation of air into a liquid to form a stable foam (Zielińska, 2022) [86]. Emulsifying Properties: Chickpea protein contains both hydrophilic (water-attracting) and hydrophobic (oil-attracting) regions in its structure. This unique composition allows chickpea protein to interact with both water and oil phases, facilitating the formation and stabilization of emulsions (Mousazadeh *et al.*, 2018) [60]. When chickpea protein is added to an oil-water mixture and agitated, it forms a stable emulsion by surrounding oil droplets with a protein layer, preventing coalescence and separation of the two phases. This property is particularly useful in salad dressings, mayonnaise, and various emulsified sauces. Foaming Properties: Chickpea protein can also generate stable foams by entrapping air bubbles within a protein network (Zhang & Lu, 2015) [84]. When chickpea protein is whipped or agitated, it forms a stable foam with a high volume and good stability. The protein film surrounding the air bubbles provides structural integrity to the foam, preventing bubble coalescence and collapse. Chickpea protein foams find applications in meringues, whipped toppings, and aerated desserts (Branch & Maria, 2017) [11]. The emulsifying and foaming properties of chickpea protein contribute to the texture, mouth feel, and stability of food products, enhancing their sensory characteristics and overall quality (Argel *et al.*,

2020) [4].

5.2 Gelation and Thickening Abilities

Chickpea protein can form gels and thicken solutions, making it a valuable texturizing agent in various food products. Gelation: Chickpea protein can form gels when exposed to heat or changes in pH (Mefleh *et al*., 2022) [55]. The protein molecules undergo conformational changes, leading to the aggregation and formation of a three-dimensional protein network. The resulting gel has a solid-like structure that entraps water and other components, creating a firm and cohesive texture (Navarra *et al*., 2016) [62]. Chickpea protein gels are commonly used in meat analogs, vegetarian sausages, and plant-based burgers to mimic the texture of meat. Thickening Abilities: Chickpea protein can also act as a thickening agent in liquid systems. When added to a liquid, such as soups, sauces, or gravies, chickpea protein interacts with water molecules and forms a viscous solution (Singh *et al*., 2021) [72]. The thickened solution enhances the consistency and mouth feel of the product, improving its overall sensory attributes. The gelation and thickening properties of chickpea protein contribute to the structural integrity and texture of food products, allowing for the development of a wide range of plant-based and textured food applications (Himashree *et al*., 2022) [32].

5.3 Water and Oil Absorption Capacities

Chickpea protein has high water and oil absorption capacities, which are essential in food applications where moisture retention and fat binding are crucial. Water. Chickpea protein can absorb and retain large amounts of water (Grasso *et al*., 2022) [27]. When added to a food formulation, chickpea protein can bind to water, preventing its release during cooking or processing. This property is beneficial in improving the juiciness and tenderness of meat analogs and plant-based products, as well as enhancing the moisture retention in baked goods. Similarly, chickpea protein can also absorb and bind to oil. In food products, this property helps in controlling oil migration, preventing oil separation, and enhancing the overall stability of emulsions (Brewer, 2012). The oil-binding capacity of chickpea protein is particularly useful in the formulation of meat analogs and plant-based products, where fat mimicking is desired (Konstantina *et al*., 2021) [40]. Overall, the water and oil absorption capacities of chickpea protein contribute to improved texture, juiciness, and stability in a wide range of food products, making it a valuable functional ingredient in the food industry.

6. Nutritional and Health Benefits of Chickpea Protein

Chickpea protein plays a significant role in human nutrition, especially in plant-based diets, as it offers a rich source of essential amino acids, making it a complete protein. With a protein content ranging from 19% to 25%, chickpeas serve as a valuable protein source for vegetarians, vegans, and those seeking to reduce their reliance on animal-based proteins (L. Day, 2013). Moreover, chickpea protein's complete amino acid profile can be complemented with other plant-based proteins to achieve a balanced diet. Beyond its protein content, chickpeas are also rich in dietary fiber, which is essential for digestive health. Fiber promotes regular bowel movements, prevents constipation, and supports a healthy gut microbiome (Goldstein & Reifen, 2022) [26]. Additionally, chickpeas provide a host of essential nutrients, including folate, iron, magnesium, potassium, and zinc. Folate is particularly crucial during pregnancy as it supports fetal development, while iron is vital for oxygen transport in the blood, and magnesium and potassium help maintain healthy blood pressure and muscle function. Chickpea protein is also considered heart-healthy due to its relatively low saturated fat content. Diets low in saturated fat are associated with a reduced risk of cardiovascular diseases (Rajagukguk *et al*., 2021) [66]. Consuming chickpea protein as part of a balanced diet offers several potential health benefits and contributes to disease prevention. Its impact on heart health includes lowering LDL cholesterol levels and reducing the risk of heart disease. The high fiber content in chickpea protein slows down sugar absorption, aiding in blood sugar management, which is beneficial for individuals with type 2 diabetes or those at risk of developing the condition (Barman *et al*., 2019) [5]. Moreover, chickpea protein's combination of protein and fiber promotes a feeling of fullness and satiety, supporting weight management by reducing overall calorie intake. The fiber content also aids in digestive health by promoting regular bowel movements and maintaining a healthy gut microbiome. Chickpeas' antioxidant properties, attributed to compounds such as flavonoids and polyphenols, protect the body from oxidative stress and inflammation, potentially reducing the risk of chronic diseases (McCrory *et al*., 2010) [54]. Furthermore, chickpea protein contributes to bone health, as it is a source of essential minerals like calcium and magnesium, which play a vital role in maintaining healthy bones and preventing conditions like osteoporosis. In comparison to other plant-based protein sources, chickpea protein stands out for several reasons. Chickpeas generally have a higher protein content than many other plant-based foods, making them valuable for those aiming to increase protein intake in plant-based diets (Langyan *et al*., 2022) [45]. Unlike some plant-based proteins that may lack certain essential amino acids, chickpea protein is a complete protein, containing all nine essential amino acids. Chickpea protein's functional properties, such as emulsifying and foaming abilities, enhance its versatility in various food formulations and plant-based products (Chandran *et al*., 2023) [15]. Additionally, chickpea protein has lower levels of anti-nutritional factors compared to some other plant proteins, reducing interference with nutrient absorption and digestibility (Gilani *et al*., 2005) [25]. Overall, chickpea protein serves as a valuable and versatile plant-based protein source, offering a range of nutritional benefits and functional properties that contribute to overall health and well-being. When integrated into a well-balanced diet, chickpea protein plays a crucial role in meeting protein needs while promoting various health benefits.

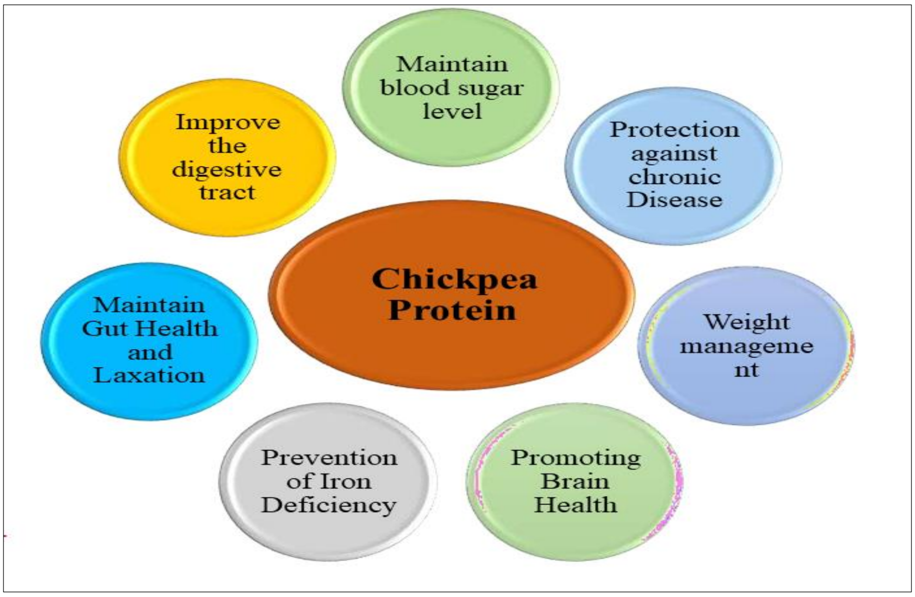

Fig 1: Health benefits of chickpea protein

7. Applications of Chickpea Protein in the Food Industry

7.1 Formulation of Meat Analogues and Plant-Based Products

Chickpea protein has gained popularity in the food industry for its role in formulating meat analogs and a wide range of plant-based products. Meat analogs are products designed to mimic the taste, texture, and appearance of meat, providing an appealing option for vegetarians and flexitarians seeking plant-based alternatives to traditional meat products (Joshi & Kumar, 2015) [36]. Chickpea protein offers several functional properties that make it suitable for these applications: Texture and Mouthfeel: Chickpea protein's ability to form gels and provide a meat-like texture makes it an excellent ingredient for creating meat analogs (Garba & Kaur, 2014) [24]. When combined with other plant-based proteins, such as soy protein or wheat gluten, chickpea protein can enhance the chewiness and juiciness of plant-based meat products. Protein Fortification: Chickpea protein's high protein content allows for effective protein fortification in plant-based products (Webb *et al*., 2023) [79]. By incorporating chickpea protein, manufacturers can increase the protein content of meat analogs and plant-based burgers, making them more nutritionally comparable to meat-based counterparts. Emulsification and Binding: Chickpea protein's emulsifying properties aid in binding fats and water, allowing for the formulation of cohesive meat analogs that retain juiciness during cooking. This is essential for achieving a satisfying mouthfeel and taste in plant-based products (He *et al*., 2020) [29]. Functional versatility: Chickpea protein can be used in various forms, such as isolates, concentrates, or textured proteins, offering flexibility in creating a wide array of plant-based products, from burgers and sausages to meatless nuggets and meatballs (Ismail *et al*., 2020) [33].

7.2 Bakery and Confectionery Products

Chickpea protein finds applications in the bakery and confectionery industry, contributing to the development of healthier and protein-enriched products. Some of its uses in this sector include Gluten-Free Bakery: Chickpea protein is gluten-free, making it an excellent alternative for individuals with gluten sensitivities or celiac disease (Grasso *et al*., 2022) [27]. It can be used as a binder and texturizing agent in gluten-free bread, cookies, and cakes, providing structure and enhancing overall product quality. Protein-Enriched Baked Goods: By incorporating chickpea protein into bakery products, manufacturers can enhance the protein content, making them more nutritious and appealing to health-conscious consumers. Protein-enriched muffins, cookies, and bars are some examples of this application (Romano *et al*., 2021) [69]. Improved Textural Properties: Chickpea protein's ability to form gels and contribute to a moist texture can improve the quality and shelf life of bakery products, providing a soft and pleasant mouthfeel (Hedayati *et al*., 2022) [30].

7.3 Beverages and Protein Supplements

Chickpea protein has also found utility in the beverage industry, contributing to the formulation of protein-rich beverages and supplements. Its functional properties allow for the creation of smooth and stable protein-based beverages with improved nutritional content: Protein Drinks: Chickpea protein isolates or concentrates can be used to create protein shakes and drinks, catering to consumers seeking convenient and plant-based protein sources for post-workout recovery or as meal replacements (Kumar *et al*., 2022) [41]. Formulation with Other Ingredients: Chickpea protein blends well with various ingredients, such as fruit flavors, sweeteners, and thickeners, resulting in appealing and flavorful protein beverages. Protein Powders and Bars: Chickpea protein can be used in the production of protein powders and bars, providing a plant-based alternative to whey or soy-based supplements (Khurana & Kanawjia, 2007) [39]. These products offer a convenient way for consumers to meet their protein requirements. Nutritional Enhancement: Chickpea protein's high protein content, combined with its fiber and mineral content, contributes to the nutritional value of protein beverages and supplements, making them more wholesome and beneficial to overall health (Vaz Patto *et al*., 2015) [76]. In summary, chickpea protein finds diverse applications in the food industry, from the formulation of meat analogs and plant-based products to enhancing the nutritional content of bakery items and beverages. Its functional properties and nutritional benefits make it a valuable ingredient for catering to the growing demand for plant-based and protein-enriched food products.

Table 2: Applications of chickpea protein

Food Products	Improved Properties	References
Cereal-based food, bakery products	Increase the nutritional value and organoleptic properties. Enhance the rheological properties, sensory analysis, and functional properties	(Joshi & Kumar, 2015) [36]
Meat Product	Improve the organoleptic characteristics, and reduce lipid oxidation. Maintain color during storage.	(Ismail *et al*., 2020) [33]
Capsule and Micronutrient supplementation	Utilized to produce protein microencapsulate for carrying nutrients because of their biocompatibility, nutritional advantages, and non-toxicity Improve stability of folate vitamin B9 by encapsulation efficiency and loading capacity	
Gluten-free muffins	Decreases the crust hardness and browning index by increasing the concentration and by decreasing the specific volume.	(Grasso *et al*., 2022) [27]
Gluten-free noodles and pasta	Decrease the glycemic index and starch digestibility Enhanced the antioxidant and protein content	(Vaz Patto *et al*., 2015) [76]
Sausage	Improved yield, increased protein content, better texture, and global acceptability	(Romano *et al*., 2021) [69]

8. Conclusions

Chickpea protein has emerged as a highly valuable and versatile ingredient in the food industry, contributing to the growing demand for plant-based and sustainable food products. Its role in formulating meat analogs and a wide range of plant-based products has significantly expanded the options available to consumers seeking healthier and more environmentally-friendly alternatives to traditional meat and dairy-based products. The functional properties of chickpea protein, such as its ability to form gels, provide texture, and emulsify fats and water, make it an ideal candidate for creating meat analogs that closely mimic the taste, texture, and mouthfeel of animal-based meats. Moreover, its protein fortification capabilities enable manufacturers to increase the protein content of various plant-based products, enhancing their nutritional value and making them more comparable to their meat-based counterparts. Beyond its use in meat analogs, chickpea protein finds applications in a wide array of plant-based products, ranging from dairy alternatives to baked goods and nutritional supplements. Its adaptability in different forms, such as isolates, concentrates, and textured proteins, allows for flexibility in creating innovative and delicious plant-based food options that cater to diverse dietary preferences. Furthermore, chickpea protein's nutritional benefits, including its complete amino acid profile, high protein content, and rich source of essential nutrients, contribute to overall health and well-being. As a complete protein, chickpea protein can be effectively combined with other plant-based proteins to ensure a balanced amino acid profile in plant-based diets. The utilization of chickpea protein in the food industry also aligns with the increasing consumer awareness of the environmental and health impacts of traditional animal-based protein consumption. Chickpeas' sustainable cultivation practices, such as nitrogen fixation and drought tolerance, contribute to more eco-friendly and resource-efficient food production.

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