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Comprehensive review on soy protein: Health benefits and utilization in food industry

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Abstract
Soybeans have been considered to be nutritious for humans. Soybean and soy product consumption has proven to have various potential health benefits and in reduction of various chronic illness. Various plant sources are examined to determine whether they may replace traditional animal based proteins for both health and environmental concerns. Due to high protein content and adaptability in the development of food products soy proteins are preferred by variety of communities around the world. Overall this review mainly focus on soybean products, soy protein and its contrast with animal proteins along with effect of different food processing methods on soybean protein digestibility.

Keywords: Soybean, soy milk, soy protein, tofu

Introduction

Soybean, a species of legume have a long cultivation history in Asia. Early in the 1990s, soybeans were already well-known for their high protein content and other nutritional advantages. Since most legumes lack the high protein quality that soybeans do, they make great plant-based protein sources (Chatterjee *et al.*, 2018) [4]. Proteins are frequently employed in the food business to provide a variety of nutritious diets to meet nutritional needs. Proteins are made up of amino acids that are essential for human health at all ages. Dietary proteins are the body's main source of nitrogen, and amino acids serve as the building blocks of body tissue, making physiological enzymes crucial for controlling chemical and biological reactions and maintaining proper bodily function. Plant-based proteins, as the name suggests, are proteins that can be found in plant-based foods including whole grains, legumes, and nuts. Among these, soy protein from soybeans (legumes), historically found in Asia, is regarded as a crucial food source to satisfy the body's need for protein (Rizzo & Baroni, 2018) [33]. Due to its many benefits, soy protein is now widely used and produced in western nations, particularly the United States (US), in a variety of food items that can be purchased at supermarkets. Due to their high protein content and potential health benefits, soy-based protein products have also become the main alternative to animal foods in vegan diets (Rizzo & Baroni, 2018; Natarajan *et al.*, 2013; Sui *et al.*, 2018) [33, 24, 40]. Public interest in meat alternatives has increased, and as a response, food experts have recently begun to concentrate on the nutritional qualities and health advantages of plant-based proteins. The most widely consumed and industrially produced plant protein is thought to be soy as plant-based proteins have become popular in recent years due to the shift in specific dietary habits that most individuals are adapting to. This has mainly been fueled by the increasing number of research in plant-based proteins demonstrating their significant health benefits as compared to animal foods (Richter *et al.*, 2015; Van Vliet *et al.*, 2015) [32, 43]. One of the reasons for the rise in attention is the recently-unraveled correlation between animal protein products consumption and a higher risk of chronic diseases (Päivärinta *et al.*, 2020) [28]. Since animal-based foods, especially red and processed meat, are primarily associated with saturated fatty acids, they have become concerned about increasing certain lifestyle illnesses such as cardiovascular disease (CVD) (Richter *et al.*, 2015) [32]. According to the European Prospective Investigation into Cancer and Nutrition (EPIC) Oxford study, people who are categorized as vegetarians or vegans score higher on the food quality index and overall dietary quality profiles than people who are classed as meat eaters (McDougall, 2002) [21]. Additionally, the Iowa Women's Health Study demonstrated that, in comparison to total carbs and animal proteins, plant-based proteins had favorable benefits to reduce mortality from coronary artery disease (Hertzler *et al.*, 2020) [10]. However, a controlled study found that plant-based proteins lack several necessary amino acids (like leucine) and are poorly digestible, which results in a weaker response to the synthesis. Further research revealed that diets high in plant protein and low in carbohydrates have low mortality rates from cardiovascular illnesses. Participants in the study from the US did not produce outcomes that were comparable to those from their European counterparts (Richter *et al.*, 2015) [32]. Plant-based proteins provide superior health advantages than animal proteins, even if it is not yet clear whether plant-based protein diets can completely replace meat products. To create a sustainable food production system, plant-based proteins still have the potential to replace animal products.

The other reason for the rise in popularity of plant-based proteins is the environmental concerns that have been brought about by livestock agriculture. This concern mainly stems from three risks posed by the meat industries. First off, several natural settings are used as sources of food for millions of animals raised for meat (Harwatt, 2019; Sha & Xiong, 2020) [8, 38]. The quantity of manure that these animals create is the second issue. The higher amounts of greenhouse gases in the atmosphere are largely due to the vapors and odors from animal dung. The industry's entire contribution to climate change is the last risk (Rubio *et al.*, 2020) [34]. National and international talks about the climate have focused on the destruction of natural ecosystems and plants to make place for new livestock ranches (Van Vliet *et al.*, 2015; Harwatt, 2019) [43, 8]. As a result, increasing focus has been placed on replacing red meat with protein-rich vegetables in the search for alternative alternatives to fulfill the rising protein demands. Therefore, this review includes summary of the several food processing methods used to create soy products, as well as nutritional value and potential health advantages.

1. Comparison of Soy Proteins to Other Protein Sources

The composition of essential amino acids and the body's ability to digest the protein after consumption are generally considered indicators of protein quality. Many people believe that animal proteins, including meat, eggs, and milk, are "complete protein packages" because they include all nine essential amino acids (Shams-White *et al.*, 2018) [39]. Animal proteins, or more specifically, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine, include all nine indispensable or essential amino acids (Nosenko, 2017) [25]. The percentage of ingested amino acids that may be used by the body after digestion and absorption is known as protein digestibility. The majority of animal proteins can be used after digestion since they are often highly digestible (>95%) (Päivärinta *et al.*, 2020; Harwatt, 2019) [28, 8]. Contrarily, plant-based proteins frequently lack one or two of the required amino acids, leading to their label as "incomplete protein packages" (Nosenko, 2017) [25]. Soy protein is regarded as having a high protein quality in comparison to other plant-based proteins. Soy protein is the only one of the three plant-based proteins that has an amino acid profile identical to that of milk and whey protein. The PDCAAS (Protein Digestibility Corrected Amino Acid Score) score and soy protein digestibility are remarkably similar to those of milk and whey protein (Hertzler *et al.*, 2020; Rizzo & Baroni, 2018; Sui *et al.*, 2021) [10, 33, 40]. Analysis of the quality of soy protein also reveals a resemblance to egg protein (Rizzo & Baroni, 2018) [33]. When consumed in the right combinations, plant proteins may complement one another (Ahnen *et al.*, 2019) [2]. Methionine is abundant in grains but uncommon in legumes, while lysine is abundant in beans but uncommon in grains. Plant-based proteins frequently include higher levels of amino acids outside of the required amino acids group, although lacking one or two essential amino acids. Particularly, plant-based proteins are high in dispensable and conditionally indispensable amino acids (asparagine, glutamine, glutamic acid, alanine, serine, cysteine, tyrosine, glycine, arginine, proline, aspartic acid), whose functional advantages are crucial for human metabolic function (Hertzler *et al.*, 2020) [10]. For instance, soy protein is a good supplier of glycine and arginine, two nutrients necessary for the urea cycle and collagen formation (Sá *et al.*, 2020) [35].

Through gastrointestinal digestion, a variety of enzymes can hydrolyze proteins into peptides and amino acids (Santos-Hernández *et al.*, 2020). 75–80% versus 90–95%, plant proteins are relatively less digestible than animal proteins. Plant protein digestibility is significantly influenced by two main variables. First, plant cell walls frequently impair protein digestion, reducing the digestibility of the protein. In addition, certain substances included in plant-based proteins, referred to as antinutritional factors (ANF) (tannins, protease inhibitors, phytate, lectins, fibres, and trypsin inhibitors), may reduce the protein's ability to be digested (Sá *et al.*, 2020) [35]. However, recent research has demonstrated that a notable boost in plant protein quality can be achieved by a variety of food processing techniques. In this review, soybean protein is discussed to demonstrate the effects of various processing techniques on protein quality.

2. Composition, consumption and nutritional value of soybean

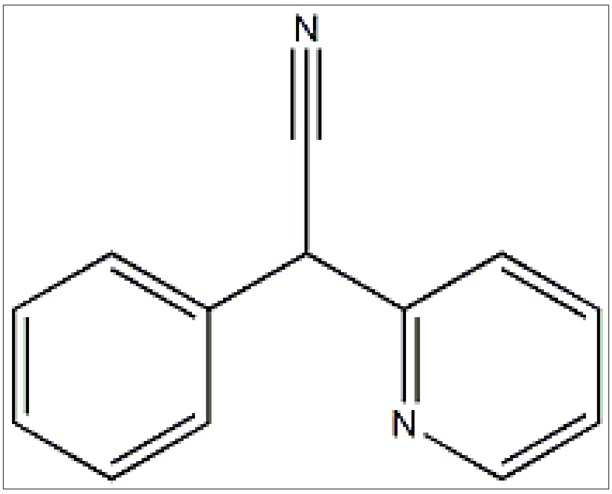

Fig 1: Soy Protein Isolate Structure

Soybeans have different protein compositions depending on the wild and cultivated habitats in which they are grown. Additionally, triggers like genetic mutation can alter the expression of soy proteins (Natarajan *et al.*, 2013) [24]. Soy protein contains two of the four protein groups: globulins and water-soluble albumins (salt soluble). Globulin is the main protein found in soybeans. Two important storage proteins, glycinin (11S) and β--conglycinin (CG, 7S), which together make between 30% and 40% of the soy protein, can be separated via ultracentrifugation (Sui *et al.*, 2021) [40].

These days, a large range of food products are made with soy-based proteins. Over the past few decades, there has been a marked growth in the production of soybeans worldwide (Pal *et al.*, 2019) [29]. With 45% of the world's soy production, the US leads the world's soy growers, followed by Brazil (20%) and China (12%). Due to a rise in US demand for the crop and its introduction into Brazil in the 1960s, soybean yields have increased globally (Cheng & Rosentrater, 2017) [5]. Tofu, soy milk, and soy sauce are just a few of the byproducts of soy that the Asian population consumes in large quantities. Vegetarians consume a lot of soy protein every day (Rizzo & Baroni, 2018) [33]. Soybeans are good source of protein, minerals, fiber and unsaturated fatty acids which depicts its high nutritional value as shown in figure 2. (Micherfelder, 2009; Velasquez & Bhathena, 2007) [22, 44].

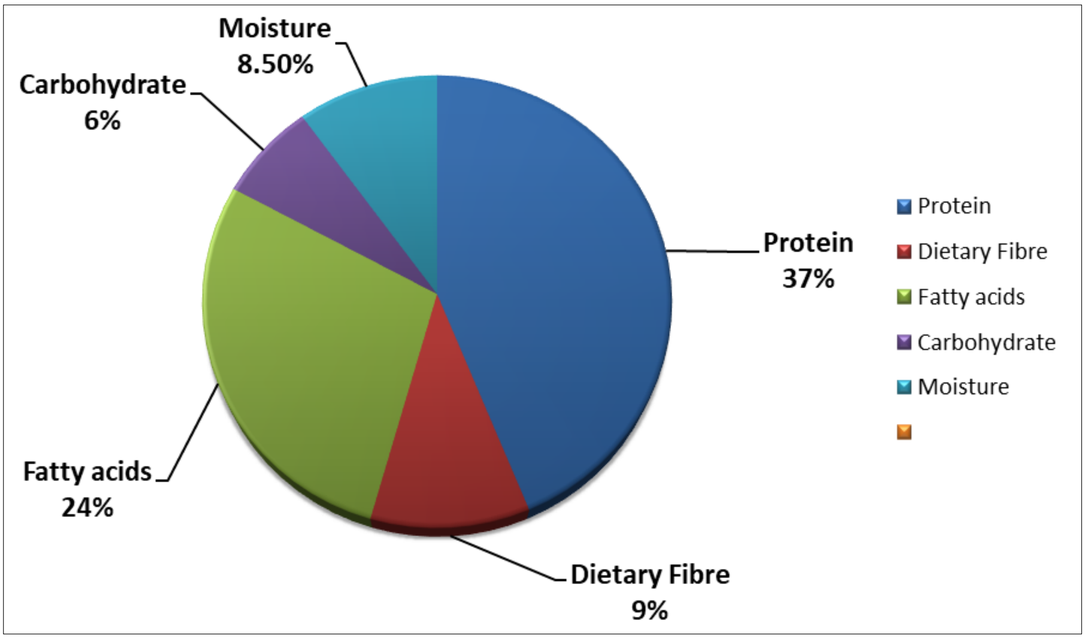

Fig 2: Nutritional composition of soybean

Health Benefits of Soy Proteins

According to Ahnen *et al.*, (2019) [2], plant protein whole foods are meals that contain plant protein and frequently have additional health advantages. Plant-based proteins are frequently ingested as part of a "mixed diet," much like meat is. The entire plant's other nutrients are likewise consumed in large quantities. The majority of these additional nutrients, including isoflavones, bioavailable iron, calcium, magnesium, dietary fibre, and polyunsaturated fatty acids, have a considerable favourable impact on human health (Nosenko, 2017; Beard *et al.*, 1996; Omoni & ALuko, 2005) [25, 6, 26]. Soy protein interacts with other substances to provide the healthful benefits on human existence. Numerous investigations on soy-based protein products have shown that they contain antioxidants (phytate, isoflavonoid) (Xu *et al.*, 2015) [50], function as tyrosine kinase protein inhibitors, control cell life, and death, reduce lipid and bile acid absorption from the gastrointestinal system, and improve anti-neoplastic enzyme activity (Rizzo & Baroni, 2018) [33].

Following that, research on soy proteins has sparked other studies in medicine and dietetics to show health benefits like lowering cholesterol, reducing menopause symptoms, preventing malignancies, and enhancing bone health. In order to increase quality of life, food products containing soybeans have been developed as a result of technological advancements (Sacks *et al.*, 2006) [36]. In an effort to lower the high amounts of cholesterol and saturated fats found in many Americans' diets, the US Food and Drug Administration approved a health claim in 1999 (Pihlanto *et al.*, 2017) [30]. According to the claim made by Amer *et al.*, (2020) [3], consuming 25 g of soy daily would greatly reduce the risk of cardiovascular disease.

5. Application and Utilization of Soy Proteins in Food Industry

With the introduction of new technologies that have improved workflows over the past ten years, the manufacturing of plant proteins has grown in popularity. As one of the most widely used alternatives to dairy milk, soy milk is a typical soy protein product. Other goods like soy sauce, meals, soy oil, and tofu are produced using a variety of processing techniques (Accoroni *et al.*, 2020) [1]. The quality of soy protein can also be increased through food processing, including cooking, soaking, germination, extrusion, fermentation, protein concentration, and isolation, with the aid of well-developed procedures.

Processes that include heating, such as cooking, irradiation, and autoclaving, are frequently used to prepare plant-based proteins. It has shown a significant reduction of toxic compounds and antinutritional factors in soy protein (Ahnen *et al.*, 2019; Sá *et al.*, 2020) [2, 35]. In order to prevent overheating that result in protein denaturation, non-thermal processing techniques like fermentation and protein isolation/concentration are used (Jan *et al.*, 2017) [13, 14].

Table 1: Effect of food processing on the digestibility of soybean (*Glycine max)*

S. No.	Food processing	Protein Evaluation Methods	Results	References
1.	Protein isolate	*In-vitro* Protein Digestibility (in %)	93	Sá *et al.*, (2020) [35]
		Protein Digestibility Corrected Amino Acid Score	100	Hughes *et al.*, (2011) [11]
2.	Protein concentrate	*In-vitro* Protein Digestibility (in %)	100	Sá *et al.*, (2020) [35]
3.	Irradiation	*In-vitro* Protein Digestibility (%)	89.3	Lee *et al.* (2012) [52]
4.	Peeling and cooked	*In-vitro* Protein Digestibility (in %)	89.8	Berno *et al.*, (2007)
5.	Autoclaving	*In-vitro* Protein Digestibility (in %)	81.3	Sá *et al.*, (2020) [35]
6.	Fermentation	*In-vitro* Protein Digestibility (in %)	90	Sá *et al.*, (2020) [35]
7.	Unfermented	*In-vitro* Protein Digestibility (in %)	83	Ojokoh & Yimin, (2011) [26]

5.1 Thermal Processing
In the production of plant-based proteins, thermal processing is frequently used, and heat can have a considerable impact on protein quality (Sá *et al.*, 2020) [35]. The best temperature for soy protein cooking is 100 °C for no longer than one hour. Large protein molecules are broken down into smaller peptides and amino acids during the heating process to improve absorption (Fawale *et al.*, 2017) [7]. Additionally, research has shown that heat considerably increases the degradation of protease inhibitors, one of the antinutritional factors that restrict the action of digestive enzymes for protein digestion (Sá *et al.*, 2020) [35]. This increases the digestibility of proteins. Overheating, on the other hand, can lead to protein aggregation, which lowers the amount of amino acids released in the intestines and lowers the bioavailability and nutritional properties of the protein (Van Der Poel, 1990) [42]. To level up protein digestibility, autoclaving, a high-pressure cooking procedure, is frequently employed to eradicate food bacteria and unwanted substances. Additionally, according to a preliminary study, 41-67% of tannins were eliminated after autoclaving, reducing their detrimental effects on plant proteins (Mansour *et al.*, 1993) [20].

5.2 Concentration/ Isolation of Proteins
Soy protein is isolated from soybean through a series of treatments, including dehulling, flaking, and defatting. Soy flour, concentrates, and isolates are three high-protein industrial products that can be produced from it. The most refined of them is soy protein isolate (SPI), which has a protein level of >90% and increased digestion (Kutzli *et al.*, 2021) [18]. SPI is created via isoelectric precipitation and alkali extraction at the proteins' isoelectric point, which is around pH 4-5. The synthesis of the SPI has a significant impact on protein digestibility in the gastrointestinal phase by removing antinutritional components and hard cell walls. At the end of the intestinal digestion, a higher level of free amino acids from SPI is released for better absorption (Santos-Hernández *et al.*, 2020). In addition, as mentioned previously, SPI mainly contains water-insoluble globulins, resulting in a high swelling property (high viscosity) (Sze-Tao & Sathe, 2000) [41]. Recently, soy-based infant formulas that are made from SPI have received increasing popularity for infant feeding to replace cow's milk due to less allergic reactions (Verduci *et al.*, 2020) [45].

5.3 Fermentation
For soy products, fermentation is a popular low-cost processing method with better bioavailability. The two main microbe strains employed in the enzymatic fermentation of soy are *Aspergillus* and *N. subtitles* (Jayachandran & Xu, 2019) [15]. Through enzymatic fermentation, soy proteins and other bigger molecules can be broken down into smaller peptides and amino acids, enhancing protein bioavailability (Sá *et al.*, 2020; Zheng *et al.*, 2020) [35, 51]. Products made from fermented soy additionally include more protein. Because fermentation is thought to be the primary processing method for producing goods that are distinctive to Eastern culture, it is also a common practice throughout Asia (He & Chung, 2020). The production of fermented soybeans using the pasting method is one of the numerous conventional technologies that have since been developed (Xie *et al.*, 2019) [49]. This has influenced Asian nations' typical preference for plant proteins over animal proteins.

One of the most often used fermented soy products for seasoning meals in Asian culture is probably soy sauce. The sauce is often made by fermenting soybean paste and toasted grains in brine while having specific fungi present (Kiarie *et al.*, 2020; Jang *et al.*, 2021) [17]. One of the fungal strains utilized in the production of soy sauce is *Aspergillus*. *Aspergillus* could aid in protein breakdown and simultaneously encourage the formation of antioxidants during fermentation. Only 2.67% of the total isoflavones were found in soy flour, whereas *Aspergillus* fermentation for 48 hours boosted this percentage to 75% (Jang *et al.*, 2021). Shoyu, teriyaka, and tamari are the three basic types of soy sauce (Jayachandran & Xu, 2019; Ashaolu, 2020) [15]. While Teriyaki is prepared from combining soy sauce with several other elements such as sugar, vinegar, and spices, Shoyu is a mixture of soybeans and wheat. Tamari is a by-product of tofu, another soy-based food (Jayachandran & Xu, 2019; Moure *et al.*, 2016) [15]. Tempeh is a soy food that is typically fermented and pressed into a cake or bar with a chunky consistency and nutty flavor (Watanabe *et al.*, 2007) [48]. Tempeh is manufactured from wheat and other whole grains like millet and rice.

5.4 Unfermented Food Products
Another popular soy-based protein product is tofu, which is manufactured from soybeans by pulverizing soaked seeds with water to produce soy milk (Jooyandeh, 2011) [16]. Coagulants help the production of curds to be gathered and squeezed as the filtered milk is heated. In China, this procedure has not significantly changed throughout time. Nevertheless, in order to speed up and improve the process, it has been mechanized utilizing cutting-edge technologies. Tofu and soymilk are consumed most widely in China, followed by Japan, Singapore, and Korea (Xie *et al.*, 2019; Pal *et al.*, 2019) [49, 29]. As a byproduct of the curdling procedure, tofu is marinated in a mild sauce. It soon takes on flavors and spicy characteristics.

Tofu being a great source of alternative protein for vegetarians because is abundant in high-quality proteins, B vitamins, and less sodium (Lusas & Riaz, 2015) [19]. However, manufacturing tofu is a labor-intensive procedure. Tofu manufacturing procedures are essential for its manufacture, from seed selection to the final packaging stage, and the quality can vary based on the specific process variables. Tofu is made from soymilk using salts and acids, two common types of coagulants. The main variables that might affect the tofu's texture, nutritional content, and flavor are temperature, coagulant, and pH, and each stage is meticulously controlled to ensure the optimum outcomes (Zheng *et al.*, 2020; Wang *et al.*, 2020) [51, 46, 47]. There are two main types of tofu. The first is also referred to as silken tofu. Extra firm tofu with little fat serves as the main ingredient. For its silky, creamy, and jelly-like texture, silken tofu is well-known (Ito *et al.*, 2013) [12]. Water-packed tofu is the alternative type of tofu. Smooth, firm, and extra firm are the three basic variations. Water-packed tofu has a more substantial and dense texture compared to silken tofu, which enables it to hold up better when cooked for stir-fry meals, soups, and grills (Riaz, 2019) [31]. Unfermented soy-based protein products like soymilk are widely available and may be purchased in every grocery store (Jooyandeh, 2011) [16]. Making soy milk from plant alternatives is simple technologically (Zheng *et al.*, 2020) [51]. Soy milk that has been fortified is known to complement micronutrients. They can be put into unrefrigerated cans or dairy packs. For people who are recognized lactose intolerant, they make the best replacements (Sethi *et al.*, 2016) [37].

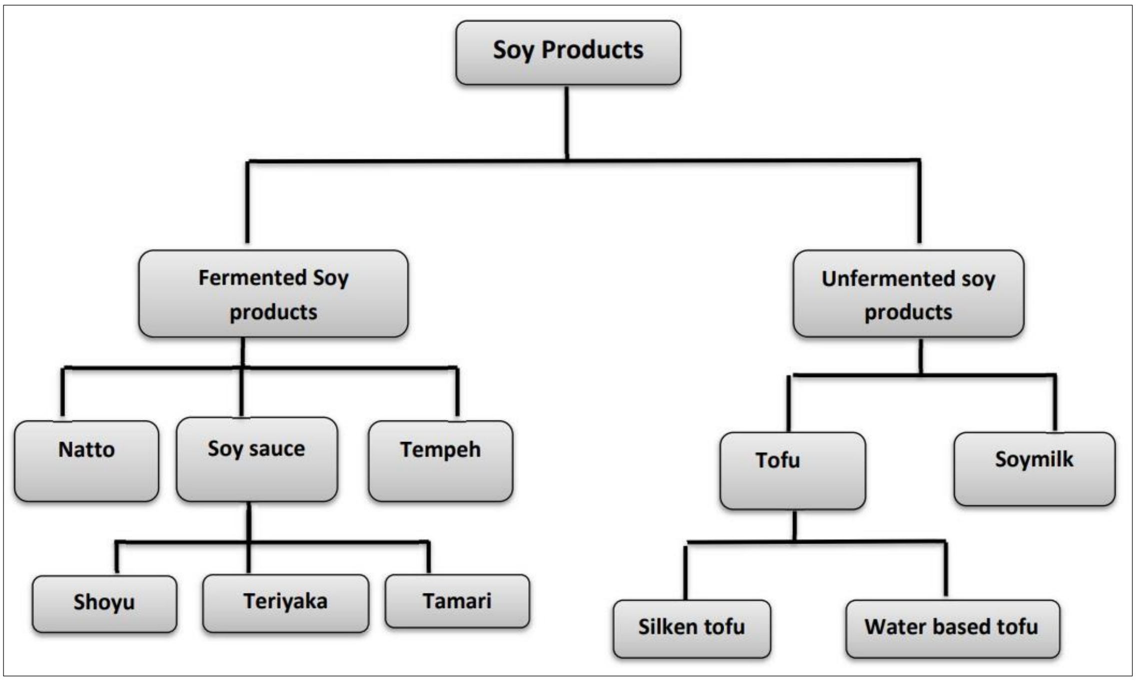

Fig 3: Flow diagram of different types of soybean products.

Conclusion

In conclusion, soy foods and soybean products have a positive impact in human welfare. Soybean has proven to be an excellent nutrient source. The popularity of plant-based whole foods and plant-based protein products is expected to continue as more studies highlight their advantages over animal protein food items, both in terms of human health and environmental sustainability. However, variable plant food sources have different levels of plant protein quality, which motivates food experts to investigate alternative strategies to enhance the quality of vegetable protein, particularly digestibility. Consuming more soy protein has been found to reduce the risk of developing chronic illnesses, including cancer and cardiovascular disease, and improve the health of menopausal women and prevent osteoporosis. Nevertheless, further research is still needed to fully understand the usefulness of plant protein properties and their related structural makeup.

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