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A review on plant-based proteins from soybean: Health benefits and soy product development

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A R T I C L E I N F O

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A B S T R A C T

Proteins are essential to human nutrition and health, and it is crucial for the development of the human body. While animal proteins are considered to be the primary dietary protein source for decades, there is a paradigm shift in recent years on the dietary consumption patterns among the general population towards plant-based food proteins. As a result, plant protein production in the food industry has skyrocketed. Research has led to a closer look at diverse plant sources and their capacity to replace conventional animal-based proteins for health and environmental reasons. Soy protein is a high-quality protein with a protein digestibility-corrected amino acid score (PDCAAS) of 1.00, which is close to some of the proteins from animal sources, such as meat and dairy. Soy proteins contain well-balanced essential amino acids except for sulfur-containing ones like methionine. They also have desirable textures with endless possibilities to formulate various sophisticated soy-based food products. Due to their high protein content and versatility in developing food products, soy proteins are the primary supply of plant-based proteins and are widely consumed by diverse populations worldwide. This review first briefly compared plant-based proteins with animal proteins regarding their health and environmental benefits, amino acid composition, and protein digestibility. As one of the most popular plant proteins, soy protein was introduced, and its byproducts-making processes (heat processing, protein isolation, and fermentation) were discussed in detail. Finally, the relationship between soy protein consumption and chronic diseases such as cardiovascular diseases, women menopausal symptoms, osteoporosis, cancer, and abdominal body fat, was highlighted by analyzing recent clinical studies.

1. Introduction

Proteins consist of amino acids vital for human health at all ages and are widely used in the food industry to formulate various healthy diets for nutritional demand. Dietary proteins are the primary nitrogen source, and amino acids act as building blocks for body tissue and make physiological enzymes essential in regulating chemical and biological reactions to keep the body functioning correctly. The Protein Digestibility Corrected Amino Acid Score (PDCAAS) is used for protein quality evaluation, based on the essential amino acid content and true fecal protein digestibility [1]. Besides, proteins are widely used as surface-active agents in the food industry due to their amphiphilic nature [2]. Even though animal proteins are good protein sources for food production, they have raised particular environmental issues for sustainability such as the increased greenhouse gas emissions during meat production. In addition, long-term red meat consumption can increase the risk of chronic disease [1,3]. Substituting animal proteins in the diet but maintaining the nutritional demands has been extensively researched in recent years. As a result, there has been a trend toward a transition from animal proteins to plant-based proteins around the globe, especially in western countries.

As the name referred, plant-based proteins are proteins found in the plant food sources, such as whole grain, legumes, and nuts. Among them, soy protein from soybeans (legumes), historically identified in the Asian region, is considered as an important food source to meet protein demand for the human body [4]. Due to its numerous advantages, the consumption and production of soy protein nowadays have been increased tremendously in western countries, especially in the United States (US), with various food products found in the grocery store. In addition, vegan dietary regimes have regarded soy-based protein products as the primary substitute for animal meats due to the high protein contents and potential health benefits [4–6]. Increased consumption of meat protein substitutes has aroused public interest, and as a result, food scientists have recently started to focus on the nutritional properties and

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health benefits of plant-based proteins. Soy has been regarded as the most popular plant protein with the highest industrial production. In this review, various food processing techniques to manufacture soy products are summarized and their recent research studies on their nutritional properties and health benefits via clinical trials are highlighted.

1.1. Rise of plant-based protein popularity

As mentioned earlier, 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 [7–9]. 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 [10]. 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) [7] The European Prospective Investigation into Cancer and Nutrition (EPIC) Oxford study showed that when comparing the food quality index and overall dietary quality profiles, individuals classified as non-meat eaters ranked higher scores than those considered as meat-eaters [11]. In addition, the Iowa Women's Health Study showed that plant-based proteins had favorable effects to reduce mortality from coronary artery disease compared to total carbohydrates and animal proteins [1]. However, a controlled study revealed that plant-based proteins lack certain (leucine) essential amino acids, and have low digestibility, leading to a weak muscle protein synthetic response compared to animal protein sources [9]. Further investigations showed that low carbohydrate plant protein-based diets resulted in low mortality rates in cardiovascular diseases. In the study, participants in the US did not yield similar results with their European counterparts [7]. Although it is not conclusive that plant-based protein diets can fully replace meat products, they have better health-promoting benefits over animal proteins. Plant-based proteins still hold the promising potential to substitute animal products to achieve a sustainable food production system.

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. Firstly, lots of natural environments are turned into feeding sources for millions of animals kept for meat [12,13]. The second concern is the amount of manure these animals produce. The gases and fumes from animal manure have contributed to the increased levels of greenhouse gases in the world. The final risk relates to the overall climate change that the industry is responsible for [3,14]. The vegetation and natural habitats that are destroyed to make room for more meat farms have been the subject of climate-based discussions both nationally and internationally [9,12]. Thus, searching for alternative solutions to meet the increased protein demands, more attention has been drawn to substitute red meat with protein-rich plants.

1.2. Comparison of animal and plant-based proteins

Protein quality generally relates to its composition of essential amino acids and its digestibility in the human body after consumption. Animal proteins, such as meat, eggs, and milk, are widely considered to have complete amino acids, known as "complete protein packages" [8]. In other words, animal proteins contain all of nine indispensable or essential amino acids, i.e., histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine [15]. Protein digestibility indicates the proportion of ingested amino acids that can be made available for utilization by the body after digestion and absorption. In general, animal proteins have a high digestibility (>95%), meaning that most animal proteins can be utilized after digestion [10, 12].

Plant-based proteins, on the other hand, are often lacking one or two of the essential amino acids, which therefore have been regarded as "incomplete protein packages" [15]. Compared to other plant-based proteins, soy protein, is considered to have a high protein quality. Table 1 summarizes the protein quality of whey, milk, and some plant protein sources, including soy, pea, and barley. Soy and pea are legumes that lack sulfur-containing amino acids (SAA), such as methionine and cysteine SAA, and grains like barley have a limited amount of lysine. Whey proteins contain a lower amount of histidine. Among the three plant-based proteins, soy protein is the one that has similar amino acids composition compared to milk and whey protein. The PDCAAS score and digestibility rate of soy protein are very similar to milk and whey protein [1,4,6]. Analysis of soy protein quality also indicates a similarity to egg protein [4].

Plant proteins, when consumed in appropriate combinations, could be complementary to each other [3]. Lysine is rich in beans but not common in grains, and methionine is high in grains but not commonly seen in legumes. Despite lacking one or two of essential amino acids, plant-based proteins often come with higher amounts of amino acids that fall outside of the indispensable amino acids group. Specifically, dispensable and conditionally indispensable amino acids (asparagine, glutamine, glutamic acid, alanine, serine, cysteine, tyrosine, glycine, arginine, proline, aspartic acid) are high in plant-based protein, and their functional benefits are critical for human metabolic function [1]. Soy protein, for instance, is a good source of arginine and glycine, which are essential nutrients in the urea cycle and collagen synthesis [16].

Proteins can be hydrolyzed into peptides and amino acids by various enzymes through gastrointestinal digestion [17]. Plant proteins have relatively low digestibility compared to animal proteins, 75–80% versus 90–95%. There are two primary factors that have significant impact on plant protein digestibility. First, plant cell walls often can interfere with the digestion of proteins, thus lowering their digestibility. Second, some compounds in the plant-based proteins, known as antinutritional factors (ANF) (tannins, protease inhibitors, phytate, lectins, fibers, and trypsin inhibitors) could limit the protein digestibility [16]. Nevertheless, recent studies have shown that remarkable improvement in plant protein quality can be obtained by various food processing methods. In this review, soybean protein is discussed to demonstrate the effects of various processing techniques on protein quality.

2. Soybean protein

Soybeans, a species of legumes, have a long cultivation history in Asia. In the early 90s, soybeans were already known for their protein-rich composition and other nutritional benefits. As mentioned above, unlike most legumes, soybeans have a high protein quality, making soybeans and their food products excellent plant-based protein sources [18]. The soybeans contain ~35–40% protein, ~20% lipids, ~9% dietary fiber, and ~8.5% moisture based on the dry weight of mature raw seeds [19]. Different cultivation environments, such as wild and cultivation conditions, make soybeans differ in their protein compositions. Besides, stimuli like genetic modification can also change soy protein

Table 1
Protein quality of different food sources.

Protein	PDCAAS	Limiting Amino Acid (s)	Digestibility (%)
Soy	0.92–1.00	SAA	95–98
Pea	0.66–0.91	SAA, Trp	83–90
Barley	0.76–0.50	Lys	76–83
Milk	1.00	None	84–94
Whey	0.90–1.00	His	98–100

SAA: sulfur-containing amino acids. Adapted from references Hertzler ta al. (2020), Hughes et al. (2011), Rizzo & Baroni. (2018). PDCAAS, Protein Digestibility Corrected Amino Acid Score; Trp, Threonine; Lys, Lysine; His, Histidine.

expression [5]. Two out of four protein groups are found in soy protein: albumins (water-soluble) and globulins (salt soluble). The primary protein type in soybean is globulin. When treated by ultracentrifugation, two major storage proteins: glycinin (11S) and β-conglycinin (βCG, 7S), account for 30% and 40% of the soy protein, respectively, can be separated [6].

Nowadays, soy-based protein food manufacturers have produced a wide variety of food products. The global production of soybeans has significantly increased over the past decades [20]. The US is the largest grower of the soy crop, making up to 45% of the global production, followed by Brazil (20%) and China (12%) [21]. The global increase in soybean yields is due to an upsurge in demand for the crop in the USand its introduction into Brazil in the 1960s [21]. Table 2 shows a summary of the daily (g/d) consumption of the population in different countries, along with vegetarians (worldwide) as a separate group. There is no current data available for European countries as they do not have significant consumption on soy products, and so it is not listed in the table. The Asian population consumes a significant amount of soy and its byproducts like tofu, soy milk, and soy sauce. Vegetarians have a high intake of soy protein daily [4].

2.1. Soy protein applications in the food industry

The production of plant proteins has become more popular over the past decade with the development of new technologies that have made processes more efficient [22]. Soy milk is a typical soy protein product, as one of the most popular non-dairy milk substitutes. Other products such as soy oil, meals, soy sauce, and tofu are manufactured through diverse processing technologies [22]. Moreover, with well-developed techniques, quality of soy protein can be improved through food processing: cooking, soaking, germination, extrusion, fermentation, protein concentration, and isolation. Table 3 summarizes different food processing methods on soybean protein and their influence on protein digestibility. Heating treatments (cooking, irradiation, and autoclaving) are commonly involved in plant-based protein processing. It has shown a significant reduction of toxic compounds and antinutritional factors in soy protein [3,16]. Non-thermal processing methods, such as fermentation, and protein isolation/concentration, are used in soy protein product development to avoid overheating that causes protein denaturation [23].

2.1.1. Heating process

Thermal processing is commonly involved in plant-based protein manufacturing, and heat can significantly impact protein quality [16]. The most suitable soy protein cooking temperature is 100 °C for no more than 1 h. The heating process contributes to the degradation of large protein molecules to small peptides and amino acids for better absorption [27]. Moreover, studies have proved that heat can significantly induce the destruction of protease inhibitors, one of the antinutritional factors that limit digestive enzymes activity for protein digestion, thus improving protein digestibility [16]. However, overheating can cause protein aggregate, thus reducing the amount of amino acids released in the intestinal tract, lowering the bioavailability and protein nutritional values [28]. Autoclaving is a cooking technique under high pressure, and it is often used to reduce food microorganisms and undesirable compounds to level up protein digestibility. Furthermore, an early study indicated that 41–67% of tannins were destroyed after autoclaving, thus alleviating their antinutritional effects on plant proteins [29].

Table 2
Soy consumption per day.

Population	Soy and Soy Foods	Soy protein
Vegetarians	NA	8.42–9.25
United States (US)	NA	NA
Korea	21.7	7.4–8.5
Japan	50.7–102.1	6–11.3
China	23.5–135.4	2.5–10.3

Adapted from reference Rizzo & Baroni. (2018). NA, Not available.

Table 3
Influence of food processing on the soybean protein digestibility.

Food processing	Protein evaluation method	Results	References
Cooking (100 °C, 30 min)	IVPD (%)	89.8	[24]
Autoclaving (123 °C, 20 min)	IVPD (%)	81.3	[16]
Fermentation (Bacillus Natto, 25 °C, 48 h)	IVPD (%)	90	[16]
Unfermented	IVPD (%)	83	[25]
Protein isolate	IVPD (%)	93	[16]
	PDCAAS	100	[26]
Protein concentrate	IVPD (%)	100	[16]

IVPD, In vitro protein digestibility. Adapted from Sá, Moreno, and Carciofi. (2020).

2.1.2. Protein isolation/concentration

Soy protein is isolated from soybean through a series of treatments, including dehulling, flaking, and defatting. It can be processed into three high-protein commercial products: soy flour, concentrates, and isolates. Among them, soy protein isolate (SPI) is the most refined form, with a protein content >90% and improved digestibility [30]. SPI is produced by alkali extraction and isoelectric precipitation at the isoelectric point of the proteins around pH 4–5. The production process of the SPI can remove rigid cell walls and antinutritional factors, having a huge impact on protein digestibility in gastrointestinal phase. At the end of the intestinal digestion, a higher level of free amino acids from SPI is released for better absorption [17]. In addition, as mentioned previously, SPI mainly contains water-insoluble globulins, resulting in a high swelling property (high viscosity) [31]. 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 [32].

2.1.3. Fermentation

Fermentation is a commonly used low-cost processing for soy products with improved bioavailability. *Aspergillus* and *N. Subtiles* are two primary strains of microorganisms used in the enzymatic fermentation of soy [33]. Soy proteins and other larger molecules can be broken down into small peptides and amino acids through enzymatic fermentation, thus increasing protein bioavailability [16,34]. Fermented soy products also have an increased protein content. Wei & Chang (2004) reported that a soy byproduct called natto has a higher protein concentration compared to its non fermented control [35]. Later studies found that carbohydrates were the primary energy source for microorganisms during the fermentation process, and with the expense of carbohydrates, the concentrated nitrogen with a reduced carbon content resulted in a higher proportion of protein in the soy protein products [23,35]. The fermentation of soybeans is also a widespread practice in Asia because this is considered as the main processing technique to create products unique to the Eastern culture [36]. Many traditional technologies to ferment soybeans have then been developed, including the pasting process to manufacture fermented soybeans [37]. This has helped to promote a general preference of plant proteins in Asian countries over animal proteins.

Soy sauce is perhaps one of the most common fermented soy products used in Asian culture for food seasoning. The sauce is dark brown and usually prepared through fermentation of soybean paste and roasted grain in brine with the presence of certain fungi [38,39]. *Aspergillus* is one of the fungi strain used in soy sauce manufacturing. During fermenation, *Aspergillus* could help to breakdown protein and at same time promote antioxidant production. In soy flour, the free isoflavones content was only 2.67% of the total isoflavones, this number could be increased to 75% after fermentation for 48 h by *Aspergillus*[39]. Soy sauce comes in three main varieties: shoyu, teriyaka, and tamari [33, 40]. Shoyu is a blend of soybeans and wheat, while Teriyaki is made from a combination of soy sauce with several other ingredients such as sugar, vinegar, and spices. Tamari is a byproduct of another soy product known as tofu [33,41]. Tempeh is a soy product made out of wheat and other whole grain products such as millet and rice that is usually fermented and pressed into a cake or bar with a chunky consistency and a nutty flavor [42].

2.1.4. Unfermented product

Soymilk is a ubiquitous unfermented soy-based protein product that can be found everywhere in the grocery store [43]. The technology used to produce soy milk from plant substitutes is straightforward [34]. Seeds are soaked, ground in abundant water, and boiled after filtration, as seen in Fig. 1. Fortified versions of soy milk are known to contain micronutrients by supplementation. They can be packaged in dairy packs or unrefrigerated cans. They serve as perfect substitutes for individuals that are known to be lactose-intolerant [44].

Tofu, also known as soybean curd, is a soft and smooth soy product made from hot soy milk. Tofu is another common soy-based protein product made from soybeans created by grinding soaked seeds in water to make soy milk [45]. The filtered milk is boiled, and coagulants promote the formation of curds to get collected and compressed. This process has not changed much over the years in China. Nevertheless, it has become automated using advanced technologies to help make the process faster and more efficient. China is the largest global consumer of tofu and soymilk, followed by Japan, Singapore, and Korea [37,46]. The byproduct of the curdling process results in tofu with a mild-taste marinade. It quickly absorbs tastes from flavors and spices.

Tofu is rich in high-quality proteins, B vitamins, and minimal sodium [47], and importantly, it is an excellent protein alternative source for vegetarians. Tofu production has a complicated making process, though. Starting from the seed selection to the final packaging step, tofu manufacturing processes are crucial for its production, and the quality can vary depending on all individual process conditions involved. Fig. 2 shows the tofu manufacturing process. Two main types of coagulants, acids and salts are used for making tofu from soymilk. Glucono-δ-lactone (GDL) is probably the best food additive among the acid coagulants that work best in the production of tofu [34]. The finding from Wang et al. (2020) revealed that with a lower level of Leu and Tyr amino acids plus high Glu present in the seeds, an increased level of firmness of tofu could be produced [48]. Temperature, coagulant, and pH are the key factors that can affect the texture, nutritional value, and flavor of tofu, and each step is strictly regulated to maintain the best results [34,48]. Tofu mainly comes in two varieties. The first one is known as silken tofu. It is primarily made from extra firm tofu that has reduced fat. Silken tofu is known for its silky, creamy, jelly-like texture [49]. The other form of tofu is water-packed tofu. It comes in three main varieties, smooth, firm, and extra firm. Compared to silken tofu, water-packed tofu has a more solid and dense texture, which allows it to hold up well when cooked for stir-fry dishes, soups, grills [50].

3. Health benefits

Plant protein whole foods, introduced by Ahnen, Jonnalagadda, & Slavin (2019), refer to the plant protein in entire meals and it often comes with additional health benefits. Similar to meat consumption, plant-based proteins are often consumed as a "mixed diet" [3]. Many other nutrients from the entire plant are also ingested. Most of these extra components have a significant positive impact on human health, such as isoflavones, bioavailable iron, calcium, magnesium, dietary fiber, and polyunsaturated fatty acids, etc [15,51,52]. The beneficial effects of soy protein on human life are coming from the interactions with other components. Numerous investigations on soy-based protein products have shown that they contain antioxidants (phytate, isoflavonoid) [53], 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 [4]. Afterward, information on soy proteins has aroused further investigations into medicine and dietetics to demonstrate health benefits such as lowering cholesterol, decreasing symptoms of menopause, avoiding malignancies, and boosting bone health. Subsequently, scientific breakthroughs have resulted in developing food products to incorporate soybeans into regular meals to improve quality of life [54]. The US Food and Drug Administration has authorized a health claim in 1999 that attempted to reduce the amount of cholesterol, and saturated fats which were consumed at high levels in many Americans' meals [55]. The argument was that eating 25 g of soy per day would significantly lower the risk of cardiovascular disease [56].

3.1. Cardiovascular disease

Cardiovascular diseases (CVDs), such as heart disease, are the primary cause of mortality across the world. High cholesterol,

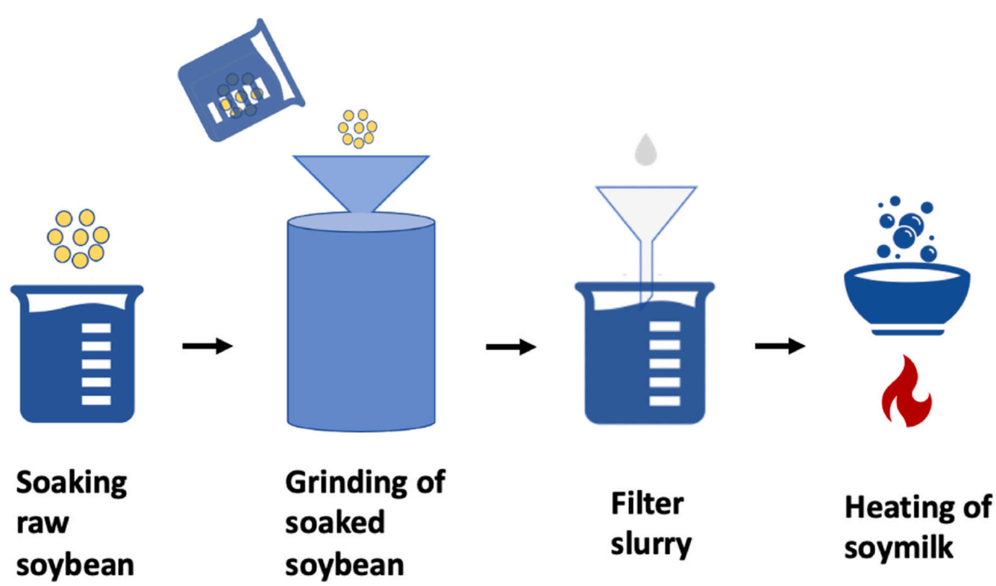

Fig. 1. Flow chart of the soymilk manufacturing process.

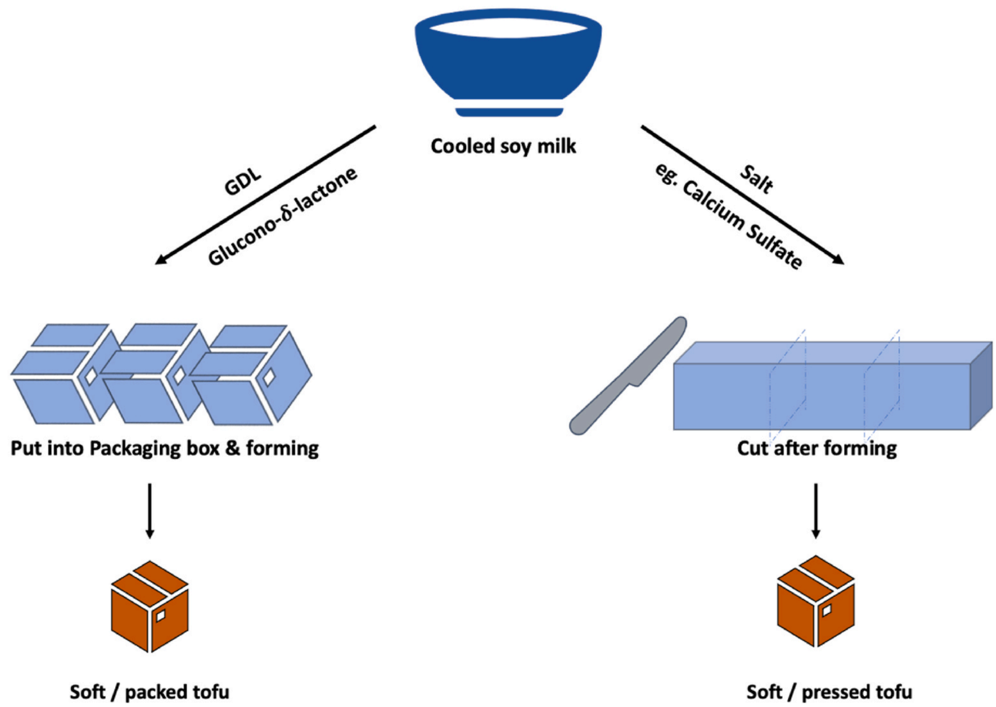

Fig. 2. Flowchart of the tofu manufacturing process.

hypertriglyceridemia, increased low-density lipoprotein cholesterol (LDL-C), reduced high-density lipoprotein cholesterol (HDL-C), high blood pressure, obesity, and diabetes are preventable risk factors for CVDs [57]. Considerable researches are suggesting that eating plant-based protein such as soy protein products instead of animal protein products decreases cholesterol levels and may have other health advantages, especially reducing the risk factors of CVDs. This is due to plant-based protein diet is considered low-saturated-fat and reduced cholesterol, thus minimizing the incidence of CVDs [58]. Additional food components like antioxidants, on the other hand, may provide extra advantages [53]. Based on epidemiologists, Asian communities that use soy as a dietary mainstay had a lower likelihood of CVD than others who follow a conventional Western diet [59].

Early researches suggested that soy protein consumption was highly beneficial to lower cholesterol, LDL, and triglycerides. Soy-based protein products were then considered to have potential benefic effects on cardiovascular health [60]. Historic studies over the last few decades uncover a strong antioxidant property of isoflavone contained in soy-based products, affecting oxidative stress and lowering cholesterol levels [60,61]. Multiple recent meta-analyses of randomized controlled trials showed an increased high-density lipoprotein cholesterol (HDL) with a lower amount of low-density cholesterol (LDL) using soy-based protein product therapy [62]. In contrast, some studies found that the intake of soy protein rich in isoflavones did not affect LDL reduction [54]. Clinical trials showed that a dose of 13–58 g of soy per day played a significant role in reducing LDL [60]. Moreover, a higher intake of fermented soy protein products showed a blood pressure-lowering effect [63]. In a populated-based cohort study in Japan, results showed a higher intake of fermented soybean protein products lower the risk of CVD mortality [64]. While soy protein appears to have beneficial effects on vascular endothelial function, the current evidence from clinical trials is not conclusive and more epidemiological studies are needed to prove the mechanistic rationale of soy protein on CVD risk factor prevention.

3.1.1. *Menopausal symptoms*

Decreased estrogen levels in menopause can cause hot flashes symptoms, genital epithelial atrophy, and osteoarthritis [65]. Estrogen treatment is considered to relieve or eliminate a majority of menopausal symptoms [66]. Isoflavones, naturally present in soybeans, have a similar chemical structure compared to estrogen. The primary underlying mechanism is dictated by the weak binding affinity between the isoflavones found in soy with estrogen receptors resulting in an estrogen-like effect [67,68]. Many researchers thus have been focusing on how isoflavones in soy can be used to manage menopausal symptoms as a safer alternative than hormone treatment [69,70]. An observational study showed a significant beneficial effect on managing hot flashes of menopausal women using isoflavones contained soy supplements [71]. Numerous initial meta-analyses of randomized placebo-controlled studies have been conducted to examine the effects of isoflavones on menopausal symptoms [72–74]. Ten studies showed a significant reduction of hot flashes reported in the treatment group (soybean rich in isoflavones) compared to the placebo group. Whereas, the results obtained from the other seven randomized controlled trials had no significant results between groups [73]. A recent systematic review on fifteen studies using a larger group of study participants with post-menopausal women was conducted by Chen, Ko, and Chen, (2019). It was concluded that women undergoing menopause who experienced hot flashes reported a reduction of symptoms after the soy product treatment compared to their counterparts in the placebo trials. Research in Chen, Ko, and Chen, (2019) demonstrates that soy protein rich in isoflavones can help with menopausal symptoms. Seventy percent [72] of participants in a survey reported their satisfaction from the isoflavones treatment. It was also shown that women in this group showed an improved quality of life during menopause [72]. Many research studies indicated the effectiveness of isoflavones-containing soy protein towards menopausal hot flashes symptoms.

3.1.2. *Osteoporosis*

During women's menopause, endogenous estrogen decline leads to an abrupt bone loss [8,75]. Hormone therapy was among the most used treatments for menopausal osteoporosis till the very last decade [76]. Soy products not only have high-quality proteins but also are rich in isoflavones and calcium. Thus soy-based protein products could contribute to bone health and prevent the risk of osteoporosis [4].

Literature reviews on meta-analysis concluded that soy protein intake affects bone mineral density [4,8]. According to several randomized controlled trials, therapeutic treatment with soy proteins rich in isoflavones showed a reduction of the bone resorption turnover rate [76,77]. In addition, a study showed that intake of soy protein results in an increased bone calcium retention in females during the post-menopausal period, reflecting a positive bone balance, thus maintaining bone volume and increasing bone strength. Moreover, as an excellent dietary source for calcium, a higher intake of soy protein and its byproducts can help meet daily calcium recommendations [76].

3.1.3. Cancer risks

Many studies indicate that cancer prevention can be achieved through healthy dietary intake. Soy products rich in various nutrients can suppress abnormal cells division and spreading and can act as an anti-cancer inhibitor in different types of cancer. Soy-based products are well-studied plant protein food for cancer prevention [33]. One early study from Hirota et al. (2000) had focused on the DPPH free radical scavenging activity of molecular compounds from miso, a fermented soybean product, indicating eight compounds in miso with high activity in cancer cell lines. Moreover, a compound called 8-hydroxydaidzein showed the highest DPPH free radical scavenging activity on human promyelocytic leukemia cells [78]. Furthermore, a study by Sharp et al. (2005) discovered that miso intake may reduce the risk of Hepatocellular carcinoma (HCC) incidence, and indicting miso may have an effect on tumor cells and cell proliferation [79]. Besides miso, other soy products also showed a positive effect on cancer prevention. A study found that chungkukjang, a fermented soybean paste made in Korea, had shown a significant suppress effect on cancer cell growth in AGS human gastric adenocarcinoma cells [80]. Moreover, studies revealed that soy products may have an anti-cancer effect, which can act as an MMP-9 regulator in colorectal cancer [81].

Concurrent studies and trial cases have been conducted to determine the relationship between breast cancer and soybean products (tofu and soymilk). This is mainly because the protein structures in soy bond with estrogen to form weak bonds resulting in estrogen modifiers [18]. From a meta-analysis of twenty-one epidemiological studies, there was a 25% reduction of breast cancer risk among women who were subjected to a diet containing high quantities of soy source intake compared to those who did not [82]. A recent meta-analysis of fourteen studies (two cohort and twelve case-control studies) indicate tofu intake is inversely associated with breast cancer risk [83].

Several studies and trials have been carried out to test the effects of soy in the prevention and management of cancer among various populations, and Table 4 lists soy products and their cancer prevention effects. One meta-study showed that the cases of prostate cancer were significantly lower in the populations who had a higher consumption rate of soy especially non-fermented soy protein products [84]. Another meta-analysis revealed that a high level of non-fermented soy protein consumption reduced gastric cancer risk [85]. It was found that the consumption of soy is ten to fifteen times higher in the Chinese and Japanese populations than in Western people. However, it was established that Asian immigrants have the same rates of prostate cancer as US citizens due to the changes in their dietary patterns after adapting to the western lifestyle [86]. Unfortunately, the studies on the relationship between soy consumption and prostate cancer management and reduction have not yielded convincing results that can be used to either substantiate or negate such claims [18].

Table 4
Soybean products and their health benefits on cancer prevention.

Author, Year	Country/ Study period	Study type	Cases/ Sample	Consumption	Preventive effects
[79]	Japan 1964–1988	Cohort based case-control	176/ 736	Tofu, natto, miso	Hepatocellular carcinoma
[87]	Japan 1996–2002	Case-control	140/ 280	Tofu, natto, soy	Prostate cancer
[88]	USA 1999–2009	Cohort	1388/ 29361	Total soy	Prostate cancer
[89]	Japan 2003–2005	Case-control	678/ 4060	Tofu, natto, miso	Breast cancer
[90]	Malaysia 2002–2016	Case-control	3683/ 7663	Soymilk	Breast cancer
[91]	Korea 2000–2005	Case-control	471/ 1236	Non-fermented soybean foods	Gastric cancer

3.1.4. Abdominal body fat

The efficacy of consuming soy protein on fat loss and preventing obesity has been demonstrated in animal and human research [92]. Daily consumption of soy protein has been studied for its nutritive value and potent antioxidant benefits for many years [51]. Several hypotheses for the anti-obesity impact of soy proteins include restriction of hepatic lipogenic enzymes and FA production, simulation of muscular FA oxidation, enhancement of plasma adiponectin levels, and enhanced fecal matter excretion [93]. Dietary intake high in soy protein could have the potential to prevent hyperlipidemia and obesity.

The impact of soy intake on weight and other obesity-related characteristics has been investigated to unravel the underlying mechanisms by which soy products exert such health benefits. An early study showed that soy isoflavones activate the peroxisome proliferator-activated receptor, thus improving lipid metabolism and generating anti-diabetic benefits [94]. Furthermore, researches proved that soy protein products rich in isoflavones have an anti-diabetic effect by suppressing insulin resistance [95]. Kim et al. (2008) found that fermented soy product Chungkukjang can regulate the blood glucose and increase the plasma insulin levels in mice, thus ameliorating the symptoms of diabetes [96]. A higher intake level of soymilk in human trials showed a reduction of oxidative stress in the type 2 diabetes mellitus population [33,97]. In addition, soy isoflavones have demonstrated potent effects on reducing cholesterol levels in both animal and human trials, and such beneficial effects are significantly enhanced when consuming soy protein in the diet compared to purified bioactive compounds [98–100]. Studies in the clinical study discovered that postmenopausal women who took soy-based meals every day for three months gained less belly fat than those who took average food [74].

4. Conclusions

With increased popularity, plant-based protein products and plant-based whole food intakes are growing rapidly worldwide in the marketplace, and such trend is expected to continue with more researches reporting their beneficial effects on both human health and environmental sustainability compared to animal protein food products. Plant protein quality varies among different plant food sources, and in many cases, most plant proteins lack certain essential amino acids and have low digestibility compared to animal protein. This challenge inspires food scientists to study various approaches to improving vegetable protein quality, especially digestibility. Soy, one of the well-studied plant protein sources, has been cultivated and consumed for centuries as an animal protein substitute for diverse populations, vegetarian and Asian populations. Although soy protein lacks some of the SAA, they still have the highest protein quality among plant proteins and the protein quality is comparable to some animal proteins. Food manufacturing processes for soy protein products are well established. Food processing methods aiming to improve soy protein quality include breaking down protein into smaller peptides and destructing compounds that interfere with protein digestion called antinutritional factors, thus increasing protein digestibility. Additionally, clinical trials have been demonstrated that higher soy protein consumption is related to lower the risk of chronic diseases such as CVD and cancer. Soy protein rich in isoflavones has shown significant health improvement for women in the menopause phase and prevents osteoporosis. Even though many studies show evidence of positive health effects of soy protein, there is still more space to be explored. There is more to say about plant protein structure and its related property functionality. Moreover, plant protein-related food allergies also need to be discussed in the future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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