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SOY PROTEIN

1. SOY PROTEIN
2. PROTEIN QUALITY
3. HEALTH IMPACT
4. ENVIRONMENTAL IMPACT
5. FOOD SAFETY OF GENETICALLY MODIFIED SOY
6. ACCESSIBILITY

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1. Soy Protein Products

Soybean (Glycine max) is one of the main sources of plant-based protein worldwide, recognized for its nutritional value, technological versatility, and relevance in human and animal nutrition.

From the soybean seed, different fractions and protein products are obtained. Among these, soybean meal (with a protein content close to 50%), soy protein concentrates (with a protein content of 65–75%), and soy protein isolates (with a protein content exceeding 90%) are particularly noteworthy.

As protein concentration increases from meals to isolates, the proportion of other components such as fiber and carbohydrates decreases. These derivatives differ not only in their nutritional composition but also in their techno-functional properties and industrial applications.

Textured soy products, produced through extrusion processes that generate fibrous structures capable of mimicking meat texture, have gained increasing interest as ingredients for the development of meat analogues and innovative products that respond to the growing demand for plant-based proteins in healthier and more sustainable diets.

2. Protein Quality

Indispensable amino acids (also referred to as essential amino acids) constitute the basis for evaluating protein quality, as the human body lacks the metabolic pathways required to synthesize them and therefore they must be obtained through the diet. If any indispensable amino acid is present in a proportion lower than that required by the organism, it becomes the limiting amino acid.

Amino acid profiles are compared against the reference pattern of indispensable amino acid requirements established by the FAO (2013)[1]. As shown in Table 1, the amino acid profile of soy protein (USDA Database) is of high quality and meets the indispensable amino acid requirements established by the FAO for adults and children over 3 years of age (Table 2).

In the case of children under 3 years of age, sulfur-containing amino acids—methionine and cysteine—are limiting. For this reason, infant formulas are supplemented with L-methionine.

Table 1. Indispensable amino acid requirement values according to FAO 2013[1] (mg/g protein) for all age groups. Soy protein values (mg/g protein) are obtained from the USDA database

Essential amino acid composition (USDA Database): AASoy		**Essential amino acid requirements (mg/g of protein) by age group (FAO 2013): AAreq**			
Essential amino acids	mg/g of protein	0–0.5 years	1–2 years	3–14 years	>18 years
Histidine (His)	23,03	20	18	16	15
Isoleucine (Ile)	42,53	32	31	30	30
Leucine (Leu)	67,83	66	63	61	59
Lysine (Lys)	53,27	57	52	38	45
Sulfur compounds (Met and Cis)	21,76	27	25	23	22
Aromatic Amino Acids (Phenylalanine + Tyrosine)	78,15	52	46	41	38
Threonine (Thr)	31.37	31	27	25	23
Tryptophan (Trp)	11,16	8.5	7	6.6	6
Valina (Val)	40,98	43	41	40	39

Table 2. Index of Essential Amino Acids.

essential amino acids	Index of essential amino acids (AAsoja/AAreq)*100			
Essential amino acids	0–0.5 years	1–2 years	3–14 years	>18 years
Histidine (His)	115	128	143	153
Isoleucine (Ile)	133	137	142	142
Leucine (Leu)	103	108	111	115
Lysine (Lys)	93	102	140	118
Sulfur compounds (Met and Cis)	81	87	95	99
Aromatic Amino Acids (Phenylalanine + Tyrosine)	150	170	191	205
Threonine (Thr)	102	116	126	137
Tryptophan (Trp)	131	159	169	186
Valina (Val)	95	100	102	105

To determine protein quality, the FAO (2013) recommended the Digestible Indispensable Amino Acid Score (DIAAS) as the gold standard [1]. This index takes into account not only the quantity of

[1] *Food and Agriculture Organization of the United Nations (FAO). 2013. Dietary protein quality evaluation in human nutrition. Report of an FAO expert consultation.*

indispensable amino acids present in a protein, but also the true digestibility of each amino acid at the ileal level of the small intestine [2].

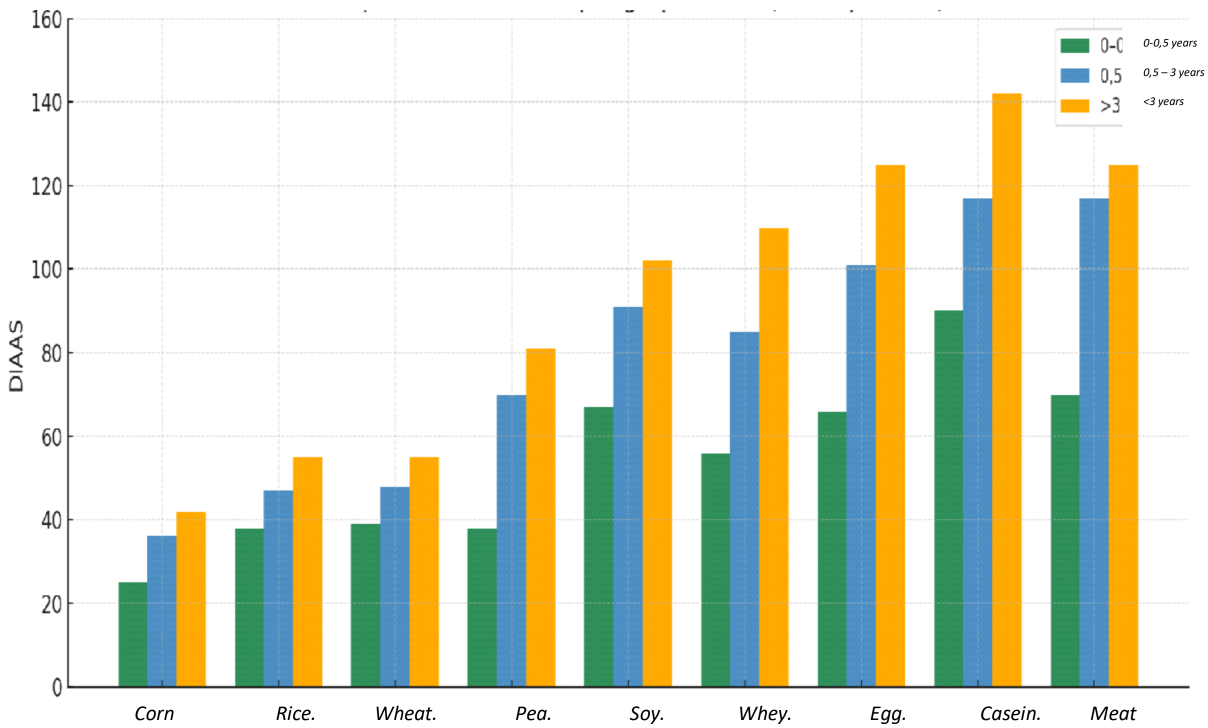
Protein quality varies significantly depending on the protein source and the degree of processing, with a value of 100 corresponding to proteins of excellent quality. As shown in Figure 1, soy protein can be considered a protein of excellent quality for age groups older than 3 years.

When the DIAAS of other plant proteins such as corn, rice, and wheat—which are part of the traditional diet (pasta, baked goods, etc.)—is compared with that of soy protein, soy protein exhibits a markedly superior quality, comparable to that of animal proteins such as whey protein. However, combinations of soy protein with cereal proteins are preferable to ensure a more complete amino acid supply for populations that follow vegetarian or vegan diets.

In addition, as indicated in Figure 1, soy protein shows higher protein quality than other legume proteins, such as pea protein[3].

[2] *Matthews J.J., Arentson-Lantz E.J., Moughan P.J., Wolfe R.R., Ferrando A.A., Church D.D. 2025. Understanding Dietary Protein Quality: Digestible Indispensable Amino Acid Score and Beyond. The Journal of Nutrition.*
[3] Herreman L, Nommensen P, Pennings B, Laus MC. 2020. Comprehensive overview of the quality of plant- and animal-sourced proteins based on the digestible indispensable amino acid score. Food Science and Nutrition.

Figure 1. Average DIAAS according to age groups (FAO 2013).



3. Health Impact

Soy protein products, due to their plant-based origin, do not contribute cholesterol to the diet, which is beneficial for the prevention of cardiovascular diseases. In addition, they contain dietary fiber, which contributes to digestive health, helps control serum cholesterol levels, and supports a balanced diet. These characteristics reinforce their value as a nutritional alternative to animal-derived proteins. Furthermore, since soy products do not provide starch, they can be incorporated into low-glycemic diets.

Cardiovascular Disease

Clinical studies in humans consistently indicate that soy protein consumption is associated with cardiovascular benefits, particularly when included as part of a balanced diet low in saturated fats. In patients with hypercholesterolemia, replacing animal proteins with soy protein (20–40 g per day) over periods of weeks or months results in small but statistically significant reductions in LDL cholesterol and total cholesterol (3–10%).

Compared with non-plant proteins[4,] soy protein produces modest but consistent reductions in cholesterol levels. These findings support dietary recommendations that promote the inclusion of plant-based proteins, such as soy protein, to improve lipid profiles.

In line with this clinical evidence, in vitro studies have shown that soy protein and the peptides generated during its digestion can reduce the intestinal bioaccessibility of cholesterol through two main mechanisms [5-6:] (a) by decreasing cholesterol solubility in bile salt micelles, whose function is to transport cholesterol for intestinal absorption, and (b) by partially sequestering bile salts, which forces the liver to synthesize new bile acids from endogenous cholesterol, thereby promoting its reduction.

These mechanistic findings support the effects observed in humans and help explain how soy protein may contribute to the reduction of circulating cholesterol levels. In addition, soy protein is a valuable ally in improving the absorption of healthy fats, such as olive oil and omega-3 fatty acids[7.]

Furthermore, the fiber present in soy concentrates and soy flours, whether textured or non-textured, also binds bile salts, increases intestinal viscosity, and, upon fermentation, produces short-chain fatty acids that inhibit hepatic cholesterol synthesis[8.] Therefore, protein and fiber act in a complementary manner, enhancing the hypocholesterolemic effect of soy-based products.

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[4] *Blanco Mejia S., Messina M., Li S.S., Viguiliouk E., Chiavaroli L., Khan T.A., Srichaikul K., Mirrahimi A., Sievenpiper J.L., Kris-Etherton P., Jenkins D.J.A. 2019. A Meta-Analysis of 46 Studies Identified by the FDA Demonstrates that Soy Protein Decreases Circulating LDL and Total Cholesterol Concentrations in Adults. The Journal of Nutrition.*

[5] *Shimizu S., Hirano K., Saito T., Akiyama H., Shimizu K., Honda H. 2025. Identification of Soy-Derived Peptides With Micelle* Disruption Activity of Secondary Bile Acids. Food Science & Nutrition.

[6] Bellesi F.A., Pilosof A.M.R. 2021. Potential implications of food proteins-bile salts interactions. Food Hydrocolloids.

[7] Bellesi F.A., Sabena F., Herrera A.W., Pilosof A.M.R. 2025. Soy Proteins Enhance the Bioaccessibility of Oleic Acid: The Role of the Interactions with Bile Salts under In Vitro Digestion. Journal of Agricultural and Food Chemistry.

[8] Ramdath D.D., Padhi E.M., Sarfaraz S., Renwick S., Duncan A.M. 2017. Beyond the Cholesterol-Lowering Effect of Soy Protein: A Review of the Effects of Dietary Soy and Its Constituents on Risk Factors for Cardiovascular Disease. Nutrients.

These results support international nutritional guidelines that recommend increasing the intake of plant-based proteins as part of strategies to reduce cholesterol levels and cardiovascular risk[9].

Glycemic Response

Soy protein products do not contain starch, unlike cereals, and therefore have a low glycemic index, making them suitable for diets aimed at controlling glycemic load. Scientific evidence is not fully conclusive regarding the effect of soy protein on glycemic control in type 2 diabetes; however, it suggests modest potential benefits. Several medium- to long-term clinical trials have reported small improvements in fasting blood glucose or insulin sensitivity when soy protein products are incorporated into the diet of individuals with diabetes [10-11].

Soy products that contain dietary fiber may further moderate the glycemic response by slowing carbohydrate digestion and absorption [12].

Satiety

Satiety is a key factor in appetite control and body weight regulation and is mediated by hormonal signals. Dietary proteins, in particular, exert a greater satiating effect than carbohydrates or fats.

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[9] Glenn A.J., Wang F., Tessier A.-J., Manson J.E., Rimm E.B., Mukamal K.J., Sun Q., Willett W.C., Rexrode K.M., Jenkins D.J.A., Hu F.B. 2024. Dietary Plant to Animal Protein Ratio and Risk of Cardiovascular Disease in Three Prospective Cohorts. The American Journal of Clinical Nutrition.

[10] *Asbaghi O., Ashtary-Larky D., Mousa A., RezaeiKelishadi M., Moosavian S.P. 2022. The Effects of Soy Products on Cardiovascular Risk Factors in Patients with Type 2 Diabetes: A Systematic Review and Meta-analysis of Clinical Trials. Advances in Nutrition.*

[11] Zhang X.M., Zhang Y.B., Chi M.H. 2016. Soy Protein Supplementation Reduces Clinical Indices in Type 2 Diabetes and Metabolic Syndrome. Yonsei Medical Journal.

[12] Ni Y., Zheng A., Hu Y., Rong N., Zhang Q., Long W., Yang S., Nan S., Zhang L., Zhou K., Wu T., Fu Z. 2022. Compound dietary fiber and high-grade protein diet improves glycemic control and ameliorates diabetes and its comorbidities through remodeling the gut microbiota in mice. Frontiers in Nutrition.

Several clinical studies show that soy protein products induce satiety responses comparable to those of animal proteins, such as casein[13], whey protein[14], or meat[15]. Therefore, soy protein represents an effective plant-based alternative for promoting satiety.

Isoflavones

Soy products contain phytoestrogens with a chemical structure similar to that of human estrogens. Their consumption, especially in women during menopause and post-menopause, may provide health benefits. A 2025 systematic review (12 trials, 533 women) [16] observed that isoflavones significantly improved overall menopausal symptom scores, particularly reducing headaches, palpitations, and psychological symptoms such as depression. A modest positive effect on bone mass[17] was also reported.[18].

Additionally, beneficial effects on cholesterol reduction and improvement of the lipid profile have been documented [19].

4. Environmental Impact

Soy protein production is more efficient and sustainable than animal protein production. Life cycle assessments show that it has a much lower environmental impact in terms of land and water use, as well as greenhouse gas emissions, contributing to climate change mitigation. In addition, as a legume, soy fixes atmospheric nitrogen in the soil, reducing the need for synthetic fertilizers and the associated environmental pollution.

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[13] Braden M.L., Gwin J.A., Leidy H.J. 2023. Protein Source Influences Acute Appetite and Satiety but Not Subsequent Food Intake in Healthy Adults. The Journal of Nutrition.

[14] Melson C.E., Nepocatych S., Madzima T.A. 2019. The effects of whey and soy liquid breakfast on appetite response, energy metabolism, and subsequent energy intake. Nutrition.

[15] Neacsu M., Fyfe C., Horgan G., Johnstone A.M. 2014. Appetite control and biomarkers of satiety with vegetarian (soy) and meat-based high-protein diets for weight loss in obese men: a randomized crossover trial. American Journal of Clinical Nutrition.

[16] Luan H., Liu Q., Guo Y., Fan H., Lin J. 2025. Effects of soy isoflavones on menopausal symptoms in perimenopausal women: a systematic review and meta-analysis.

[17] Luan H., Liu Q., Guo Y., Fan H., Lin J. 2025. Effects of soy isoflavones on menopausal symptoms in perimenopausal women: a systematic review and meta-analysis.

[18] Sansai K, Na Takuathung M, Khatsri R, Teekachunhatean S, Hanprasertpong N, Koonrungsesomboon N. Effects of isoflavone interventions on bone mineral density in postmenopausal women: a systematic review and meta-analysis of randomized controlled trials. Osteoporos Int. 2020 Oct;31(10):1853-1864.

[19] Bellesi F.A., Pilosof A.M.R. 2021. Potential implications of food proteins-bile salts interactions. Food Hydrocolloids.

A global meta-analysis by the University of Oxford [20], including more than 38,000 farms, confirmed that soy-based foods rank among those with the lowest environmental footprints in terms of greenhouse gas emissions (up to 100 times lower than beef), land use (up to 100 times lower than beef), water consumption (beef requires up to 70 times more water than soy products to produce the same amount of protein), as well as acidification and eutrophication (80–90% lower compared to beef).

This combination of lower resource use, reduced emissions, and agronomic advantages positions soy as a strategic alternative for more sustainable food systems.

5. Food Safety of Genetically Modified Soy

More than 80% of the soy grown worldwide is genetically modified (GM)[21]. The main producing countries are Brazil, the United States, and Argentina, which together account for over 90% of total GM soy cultivation. Paraguay, Uruguay, Canada, and South Africa also allow its commercial cultivation. The European Union does not authorize the cultivation of GM soy, but it does allow its importation (for human and animal consumption) under strict regulatory control and mandatory labeling[22].

GM soy is one of the most extensively studied crops worldwide since its commercial introduction in the 1990s. International scientific evidence, supported by organizations such as FAO [23], WHO, EFSA[24] (European Food Safety Authority), and USDA[25], demonstrates that GM soy is safe for human and animal consumption. Numerous toxicological, nutritional, and multigenerational studies have confirmed that genetic modifications in soy—whether for herbicide tolerance, insect resistance, or compositional improvement—do not alter its nutritional value nor introduce risks of toxicity or allergenicity.

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[20] Poore J., Nemecek T. 2018. Reducing food's environmental impacts through producers and consumers. Science.
[21] Ashrafi-Dehkordi E. Aliborzi A., Pouladfar G., Abbasian S.A., Mazloomi SM. 2024. Effects of genetically modified soybean on physiological variables and gut microbiota of Sprague-Dawley rats. PLOS one 19(12).
[22] EFSA Panel on Genetically Modified Organisms (GMO). 2023. Scientific opinion on the renewal application for authorisation of genetically modified soybean MON 87701 × MON 89788 for food and feed uses. EFSA Journal, 21(6).
[23] FAO/WHO Codex Alimentarius Commission.Codex Alimentarius. 2003. Guidelines for the Conduct of Food Safety Assessment of Foods Derived from Recombinant-DNA Plants (CAC/GL 45-2003). FAO/WHO. https://www.fao.org/fao-who-codexalimentarius.
[24] EFSA Panel on Genetically Modified Organisms (GMO). (2022). Scientific opinion on the genetically modified soybean DBN9004 for food and feed uses under Regulation (EC) No 1829/2003. EFSA Journal, 20(10).
[25] USDA ERS. 2023. Adoption of Genetically Engineered Crops in the U.S. https://www.ers.usda.gov/dataproducts/adoption-of-genetically-engineered-crops-in-the-u-s.

More than 25 years of consumption and thousands of peer-reviewed studies confirm that no adverse effects, new allergies, or toxicity have been detected in association with GM soy consumption. Animal studies show that productive performance, fertility, and the composition of animal products (meat, milk, and eggs) are equivalent when animals are fed GM soy or conventional soy[26-27].

Taken together, the scientific community and leading regulatory agencies agree that genetic modification itself does not pose a risk to human health or food safety.

6. Accessibility

Soy protein is currently the most widely available and accessible high-quality plant protein worldwide. Its production is highly scalable, allowing for the manufacture of tens of millions of tons of protein per year. Soy protein is easy to store and transport, and its dry formats—powders and textured products—are non-perishable, enabling long shelf life.

Textured soy products, in particular, are quick and easy to rehydrate and can directly replace meat in any dish that traditionally uses ground meat. Their low economic and environmental cost allows soy protein to reach millions of people globally, especially in regions where animal protein is limited or prohibitively expensive.

Incorporating soy products into the diet not only helps reduce pressure on arable land and water resources, but also provides nutritional benefits and contributes to the prevention of non-communicable diseases.

[26] Snell, C., Bernheim, A., Bergé, J. B., Kuntz, M., Pascal, G., Paris, A., &Ricroch, A. E. 2012. Assessment of the health impact of GM plant diets in long-term and multigenerational animal feeding trials: A literature review. Food and Chemical Toxicology, 50(3–4), 1134–1148. https://doi.org/10.1016/j.fct.2011.11.048.

[27] Shi, Z., Zou, S., Lu, C., Wu, B., Huang, K., Zhao, C., & He, X. 2019. Evaluation of the effects of feeding glyphosate-tolerant soybeans (CP4 EPSPS) on the testis of male Sprague-Dawley rats. GM Crops & Food, 10(3), 181–190.

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