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PROCESSING EFFECT ON SOYBEAN NUTRIENTS AND POTENTIAL IMPACT ON CONSUMER HEALTH: REVIEW

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ABSTRACT

Global soybean production and soy product consumption are rising due to their perceived health benefits. However, processing methods can impact soy's sensory qualities, nutritional value, and consumer health. Processing soy below 100 °C for short durations generally preserves its nutritive value. Beneficial changes include heat-induced inactivation of trypsin inhibitors and denaturation of globulins and haemagglutinins, which enhance protein bioavailability. Excessive heating, however, can degrade essential amino acids like lysine, tryptophan, and methionine. Alkali-catalyzed reactions produce lysinoalanine, a compound linked to toxicity in rats but not shown to harm humans at dietary levels. Alkaline heat treatments also degrade arginine and cysteine, and reduce serine, threonine, and lysine—conditions common in alkali-refined soy oil. The Maillard reaction, involving carbohydrates and proteins, and heat above 200 °C at alkaline pH, causes amino acid isomerization into L and D forms. D-isomers, such as D-proline, have lower bioavailability and potential toxicity. Lipid changes include oxidation, loss of lipid-soluble vitamins, and conversion of cis to trans fatty acids. Autoxidation of unsaturated fats generates free radicals, reducing essential fatty acids and contributing to atherosclerotic plaque formation. Processing also affects vitamins: carotenoids are lost during bleaching, reducing vitamin A potential, and vitamin E diminishes during oil refining. Soy isoflavones remain stable during roasting and toasting but are removed by organic solvents; fermentation boosts their bioavailability. Dehulling lowers mineral content, with sodium and potassium lost in wash water. To preserve soy's nutritional integrity, recommended practices include minimal washing, fermentation, reduced hydrogenation temperatures, and brief thermal processing below 100 °C.

Keywords: Soybean, nutrients, processing, Vitamin A, human health

INTRODUCTION

Soybeans are a globally significant crop, widely recognized for their high protein content and nutritional versatility. However, the processing of soybeans raises important considerations for nutrient retention and their impact on consumer health. While soybeans are an excellent source of plant proteins, containing beneficial compounds like isoflavones, the processing steps intended to enhance their digestibility and bioavailability can lead to nutrient loss and affect their health benefits (Hwang *et al.,* 2018). Cooking, steaming, and fermentation are common techniques that aim to inactivate anti-nutritional factors such as protease inhibitors and lectins, which are present in raw soybeans. These processes not only enhance the taste and shelf-life of soy products but also influence the nutritional profile of the final product (Di *et al.,* 2024).

There are many procedures that food raw materials go through before they are finally available as edible food products. In food processing, these procedures are commonly referred to as unit operations. They include: cleaning, coating, concentrating, heating and cooling (heat exchange), drying, disintegrating, mixing, pumping and separating (Zhang, 2020). This order does not, however, give their natural sequence or their relative importance when applied in the preparation of food products.

Each of the above unit operations has other accompanying and minor procedures. For example, mixing includes agitating, beating, heating, blending, diffusing, dispersing, emulsifying, homogenizing, kneading, stirring, whipping and working, depending on the product being manufactured (Arijum *et al.,* 2025). The unit operations are selected and combined into more complex integrated processing systems peculiar to each factory operation to enable the conversion of food raw materials into specific end products.

Research has shown that while processing can render soy protein highly digestible and capable of delivering all essential amino acids, it also demands a careful balance as excessive or improper processing might diminish the desirable nutritional qualities such as the antioxidant properties attributed to isoflavones. Understanding the dual role of processing is necessary to optimize the health benefits of soy foods while minimizing potential adverse effects like allergenic reactions or nutrient deficiencies (Hwang *et al.,* 2018).

This overview seeks to explore the multifaceted effects of soybean processing on nutrient composition and the subsequent implications for consumer health. It aims to provide insights into how different processing methods alter the chemical structure and bioactive potential of soybeans, highlighting the need for innovative food processing strategies that preserve their nutritional integrity while enhancing their health-promoting properties (Divya *et al.,* 2022).

Trends in Soybean Production

Soybeans (*Glycine max (L) Merrill*, family *Leguminosae*) are believed to have originated in the Orient, most likely in China. In the Orient and other soybean-producing regions worldwide, the primary products derived from soybeans are oil and meal, along with various non-fermented and fermented soy foods (Ali *et al.*, 2022). The leading producers of soybeans are the United States, Brazil, Argentina, and Bolivia, in that order, while China is the largest importer of soybeans globally. In the US, Brazil, and Argentina, approximately 81%, 34%, and 99% of soybean crops are genetically modified, respectively. This means that soybean seeds or soy food imported from these countries by African processors and consumers are likely to be genetically modified.

Over the past five decades, extensive research has uncovered health benefits associated with soybeans and their products as human food, leading to increased global production and consumption. In 2007, worldwide soybean production reached 221 million metric tons (MT). Africa produced about 1.3 million MT of soybeans in 2007, accounting for roughly 0.5% of global output, which was a significant increase from 0.6 million MT in 2002, more than doubling in five years. The estimated global output for the 2009/2010 period was 259 million MT. The output of soybeans from Africa is low despite the long history of soybeans growing in Africa, dating as far back as 1889. The FAO statistics for soybeans production feature 19 African countries. In the context of African production, Nigeria leads with 49% of the output with others being Uganda (17%), South Africa (15%), Zimbabwe (8.4%), Ethiopia (2.7%), Rwanda (2.0%), Egypt (1.7%) and the Democratic Republic of Congo (1.4%) (Ariyabukalakorn *et al.*, 2019). Others with less than 1% output each include Cameroon, Zambia, Gabon, Tanzania, Liberia, Burkina Faso and Morocco.

Soybean production in Nigeria has experienced significant trends shaped by technological advancements, climate change, and agricultural policies. Historically, soybean cultivation in Nigeria has been crucial for local consumption and oil production, offering essential protein sources and enhancing food security. However, various factors have influenced production trends over the years. Two major challenges arose when introducing whole soybeans for home use in Africa. Firstly, they required a lot of time and fuel to cook. Secondly, their taste was not well-received. The extended cooking time needed to soften the soybeans can lead to nutritional changes due to the thermal effects on nutrients (Ali *et al.*, 2022).

Climate change impacts the agricultural outputs significantly, and Nigeria, being vulnerable to such changes, has experienced temperature fluctuations and variable rainfall, which directly affect soybean yield. The agricultural sector, including soybean production, is susceptible to these environmental shifts, underscoring the need for robust adaptation strategies (Ibrahim *et al.*, 2016).

Moreover, the introduction of digital agriculture technologies aims to overcome some of these challenges by enhancing efficiency and productivity through precision farming and better resource management in Nigeria. Agriculture 4.0 initiatives are being proposed to address food insecurity, incorporating sustainable practices and modern technologies to secure and potentially boost production outputs, including soybeans, post-COVID-19 (Adeyemo *et al.*, 2024).

Despite these advancements, soybean production faces policy and infrastructural hurdles which continue to challenge its expansion and optimization. The need for Nigerian policymakers to focus on sustainable agricultural practices, investment in agricultural technology, and infrastructure development is critical to overcoming these barriers and fostering a self-sufficient agricultural sector. Adopting policies that support innovations in soybean farming could strengthen Nigeria's position in the agricultural sector while ensuring resilience against future climate challenges.

Major Soybean Nutrients

Soybeans are a remarkable source of essential nutrients, offering numerous health benefits. They are known for their high-quality protein content and include all essential amino acids, which is beneficial for human health (Fernandez and Marette, 2017). Beyond protein, soybeans are rich in dietary fiber, vitamins, minerals, and a variety of bioactive compounds, such as isoflavones, phenolic acids, saponins, and phytic acid (Igbabul *et al.*, 2014). The nutritional composition of soybeans can differ based on the variety, growing season, and location. On average, soybeans contain approximately 40% protein, 20% fat, 35% carbohydrates, and 5% ash when measured on a dry weight basis. For optimal storage stability of mature soybeans, it is important to maintain a moisture content of 12-15%. The moisture level at the time of harvest is crucial for proper handling afterward.

Isoflavones in soybeans, like genistein and daidzein, have phytoestrogenic properties and are believed to reduce the risk of certain types of cancer. They are also associated with cardiovascular benefits and bone health, potentially alleviating conditions like osteoporosis (Rahman et al., 2024; (Cruz *et al.*, 2009). The presence of isoflavones and other bioactive compounds also suggests a role in managing symptoms of menopause, such as hot flashes. Soy protein is distinguished by its complete amino acid profile and high digestibility, making it an excellent option for those seeking plant-based protein alternatives. Additionally, soy protein products are widely used in food applications due to their functional properties (Jha *et al.*, 2022). Fermented soy products, such as soy sauce and tempeh, contain increased levels of bioactive peptides, which enhance their unique flavors and health benefits. These products are associated with improved nutritional value and health advantages, such as immune support and better gut health (Al-Noman *et al.*, 2025). Protein is the second most valuable component of soybeans, after oil. While soy protein complements the amino acid profile of cereals, it lacks sulfur-containing amino acids, particularly methionine, which is essential for most species, including humans.

Extracting lipids from soybeans using hexane at 60-70°C for 30-40 minutes does not adversely affect the solubility of soy protein, the enzymatic activity of defatted flour, or its trypsin inhibitor activity. Unlike other phytohaemagglutinins, soy haemagglutinins do not significantly impact the nutritional value of soybeans. Soybeans are an excellent source of lipoxygenase, which is used to bleach carotenoids in wheat flour as an alternative to bromides and similar chemicals. As soybeans mature, the content of monosaccharides decreases, while complex carbohydrates like raffinose, stachyose, and sucrose increase, typically reaching levels of 1%, 4%, and 5%, respectively, in mature beans. Although humans do not digest and absorb stachyose and raffinose as nutrients, these oligosaccharides are metabolized by intestinal microflora, leading to gas production and flatulence. The insoluble carbohydrates, mainly cellulose, hemicellulose, and pectins, serve as insoluble dietary fiber. Soybeans also provide nutritionally significant amounts of calcium and iron. However, the presence of phytic acid can negatively affect the bioavailability of some minerals, such as zinc.

Soybeans also contain anti-nutritional factors (ANFs) like trypsin inhibitors, lectins, and tannins, which can interfere with nutrient absorption when consumed in large amounts. However, these ANFs also offer potential health benefits, such as antioxidant and anti-inflammatory effects. Proper processing techniques usually mitigate the negative impacts of these ANFs, allowing the beneficial aspects of soybeans to prevail (Di *et al.*, 2024). In summary, soybeans are a highly nutritious and versatile food source, offering significant health benefits through their unique composition of proteins, dietary fiber, vitamins, minerals, and bioactive compounds. These components play a vital role in supporting cardiovascular health, bone health, cancer prevention, and overall well-being (Cao and Islam, 2024).

An Overview of Soybean Processing

Soybean processing encompasses a range of methods and techniques aimed at extracting valuable components like oil and protein while preparing the bean for various applications. The oil extraction process is a significant element of soybean processing, which typically involves three stages: preprocessing, extraction and separation, and post processing (Ahiduzzaman *et al.*, 2024).

***Oil Extraction Techniques**:* Traditionally, the hexane extraction method is used in industrial settings due to its efficiency in isolating soybean oil from the bean meal. Alternative methods, such as supercritical CO2 extraction, are being explored for their environmental benefits and potential to reduce hexane emissions (Cho *et al.*, 2020). Mechanical processes like extrusion-expelling are also employed, where the soybeans are first extruded and then mechanically pressed to express the oil. This method allows for the recovery of over 90% of the available oil under optimal conditions.

***Processing Soybean Meal**:* After oil extraction, the remaining soybean meal is valued for its high protein content and is utilized largely in animal feed. Defatted soybean meal (DSM) results from the complete extraction of oil and is preferred for its protein content. In contrast, full-fat soybean meal (FFSBM) retains some oil, offering additional energy benefits but requiring proper heat treatment to eliminate anti-nutritional factors such as protease inhibitors (Cao *et al.*, 2020).

Soy Protein Products: The production of soy protein products involves special processes to meet the specific quality requirements for use in human food. Products such as soy protein isolates, concentrates, textured proteins, and flours are produced by these specialized processes (Horan, 1974). Processing can impact the protein nutritional quality, with protein quality scores varying significantly across different soy products depending on the extent of processing and post-processing treatments (Al-Nabulsi *et al.*, 2014).

***Soybean Byproducts**:* Soya bean processing also yields byproducts such as okara, a residue rich in dietary fiber and isoflavones. Although often considered waste, these byproducts hold potential as sustainable sources of nutrients and have applications in functional foods, dietary supplements, and even cosmetics, thus contributing to environmental sustainability (Aussanasuwannakul *et al*., 2023).

***Challenges in Processing**:* Addressing challenges such as soybean allergy and the presence of anti-nutritional factors is crucial in soybean processing. Techniques like heat treatment and novel methods such as ultrasound and cold-plasma treatments are being investigated to mitigate allergenicity and improve the overall safety and nutritional quality of soybean products (Zhang *et al.*, 2020).

Effects of Processing on Soybean Nutrients

Processing techniques significantly influence the nutrient profile of soybean products, impacting both the nutritional benefits and the presence of anti-nutritional factors. Various methods like germination, fermentation, and heat treatment can enhance the nutritional quality, while also mitigating some undesirable components.

Germination: This process involves soaking soybeans to encourage sprouting. Germination increases protein, fiber, and ash content while decreasing anti-nutritional factors like trypsin inhibitors. It also enhances the levels of biologically active compounds such as saponins and phytosterols, which can improve palatability and nutritional absorption (Chauhan *et al.*, 2022).

***Dehulling**:* Removal of soybean hulls is another method that improves the nutrient profile by increasing the content of crude protein and fiber. It also helps in reducing anti-nutritional factors, thereby improving the digestibility of soybean flour.

Fermentation: Fermenting soybeans can enhance their nutritional value, as seen in black soybeans processed with Eurotium cristatum, which showed an increase in protein content, essential amino acids, and various minerals. Fermentation also raises the levels of bioactive compounds like isoflavones and phenolics, boosting antioxidant activity (Hwang *et al.,* 2018).

Heat Treatment: This method is used to address the soybean's objectionable beany flavor in soymilk, potentially reducing nutrient content. Methods involving soaking and heating in basic solutions may affect protein, fat, and mineral profiles, as well as isoflavone content (Zheng *et al.,* 2016).

Anti-Nutritional Factors (ANFs): Processing aims to deactivate ANFs such as trypsin inhibitors, lectins, and phytates, which interfere with nutrient absorption. Appropriate processing techniques can lower these ANFs, thus enhancing the overall bioavailability of nutrients in soybean products (Di *et al.*, 2024).

Environmental and Genetic Factors: The nutrient quality of soybeans is also influenced by environmental conditions and genetic variances among different soybean varieties. This variation underlines the importance of customized processing methods to optimize the nutritional quality of soybeans across different growing environments (Zheng *et al.,* 2016).

Effects of Processing Procedures on Soybean Proteins

Processing impacts soybean proteins structurally, functionally, and nutritionally. Advances in computational and image analysis have revolutionized protein characterization, enabling scalable assessment of sequence diversity and microstructural changes. High-dimensional feature extraction (60d-SPF, 6d-SCPSF) and fuzzy clustering algorithms (SRSIO-FCM, SLFCM) efficiently organize large datasets, revealing patterns linked to processing and functional potential. Digital imaging tools like the agglomeration index δ_agg objectively measure structural changes, connecting topological features to outcomes. These methods enhance understanding of processing effects and support industrial optimization, product quality improvement, and novel protein material design. Integrating information theory, big data analytics, and topological analysis opens new research frontiers. Converging experimental, computational, and theoretical approaches is key to tackling challenges in complex protein systems. Modeling and controlling processing effects will drive innovation in food science, biotechnology, and materials engineering, enabling sustainable, high-value protein products for a growing global population (Guan *et al.,* 2021).

Effects of Heat on Soybean Protein

Soybeans generally retain their nutritional value during solvent extraction if temperatures stay between 60–90°C. The thermal denaturation temperature (Td) of soybean glycinin is 92°C—higher than most pure protein isolates but lower than some other plant proteins. Desolventizing-toasting, the main heating step, improves nutritional quality by inactivating trypsin inhibitors and denaturing globulins, enhancing protein bioavailability and functional properties like foaming and emulsification. However, excessive heating—such as autoclaving at 130°C or prolonged exposure at 90–100°C—can reduce nutritional value. This occurs through acylation of free amino groups, making lysine unavailable. Lysine is particularly vulnerable due to its free epsilon amino group. High surface temperatures can convert serine, cystine, and cysteine into intermediates that react with lysine to form lysinoalanine, a potentially toxic compound. Tryptophan is also lost due to its indole group. In rats, lysinoalanine causes diarrhea and pancreatic issues, but these effects are not seen in other animals. In humans, protein-bound lysinoalanine is excreted and does not cause nephrotoxicity (Alarape *et al.,* 2024).

Effects of Alkali and Other Chemical Agents on Soybean Protein

Naturally occurring amino acids exist in the L form, which is nutritionally available. However, alkali treatment can convert them to the D isomer, reducing bioavailability. Acid hydrolysis and roasting above 200°C may also cause isomerization, though small changes are typically not harmful. The Maillard reaction, triggered by proteins reacting with carbohydrates' carbonyl groups, can make lysine unavailable. This reaction is accelerated by alkali, heat, and low moisture, so overheating soy meal should be avoided. Proteins are generally stable at neutral pH, but extreme pH—especially alkaline—causes swelling and unfolding due to high net charge. Soybean processing methods like oil extraction, bleaching, and extrusion often occur at alkaline pH, leading to amino acid loss. Alkaline conditions promote ionization of buried carboxyl, phenolic, and sulfhydryl groups, unraveling polypeptide chains. Additionally, organic solvents and detergents can denature proteins by dissolving nonpolar side chains, further affecting protein structure and nutritional quality (Shi *et al.,* 2025).

Effects of Oxidation on Soybean Protein

Heating proteins or exposing them to oxidizing agents like peroxides can degrade amino acids, especially sulfur-containing ones and tryptophan. Methionine, cysteine, tryptophan, and histidine are most prone to oxidation, with tyrosine less affected. Sulfur amino acids are limited in soy protein, so their loss impacts nutritional value. Cystine and cysteine may oxidize into cysteic acid, which is nutritionally inactive, or into usable forms like sulfenic acid and disulfoxides. Methionine sulfone is usable, but methionine sulfoxide is not. Tryptophan is easily oxidized in both acidic and alkaline conditions, especially during thermal processing. Heat above 200°C and alkaline pH can cause amino acid racemization, forming D-isomers that lack nutritional value and reduce digestibility. Amino acids like aspartic acid and serine racemize faster due to their chemical structure. Some D-amino acids, such as D-proline, are neurotoxic in chickens, though human effects are unclear. Lipids above 0.5% improve soy protein foaming, but lipid-free isolates offer better foaming performance (Dominguez et al., 2022).

Effects of Processing on Soybean Lipids

High-temperature processing of soybeans—through toasting, boiling, or extrusion—can alter lipids, affecting nutritional value and sensory appeal. Key changes include lipid oxidation, oil loss, and conversion of cis to trans fatty acids. While oil loss may slightly reduce caloric value, it rarely impacts overall dietary energy. Lipid oxidation decomposes unsaturated fatty acids into volatile compounds, causing oxidative rancidity with "grassy" off-flavours in soy foods. In soy oil, ω-6 fatty acids contribute to this effect. Lipases can also trigger hydrolytic rancidity without oxygen. Extended oxidation may generate free radicals, further degrading linolenic, linoleic, and oleic acids. Hydroperoxides react with amino acids like lysine, cysteine, and methionine, forming insoluble complexes that hinder digestion and may contribute to atherosclerosis. Refining soy oil below 100°C causes minor nutrient loss; bleaching reduces carotenoids, lowering vitamin A potential, while vitamin E remains sufficient. Roasting and toasting preserve isoflavones, but lipid solvents remove them. Hydrogenation alters fatty acid structure, reducing essential polyunsaturated fats and diminishing the oil's nutritional value (Szabo *et al.,* 2022).

Effects of Hydrogenation of Soybean Lipids on Consumer Health

Trans fatty acids occur naturally in small amounts in ruminant foods and have been consumed for centuries. However, hydrogenation of vegetable oils like soy oil and high-temperature cooking (above 220°C) can convert cis fatty acids into trans isomers, which resemble saturated fats and have higher melting points. These trans fats make oils more solid and are now a major source in human diets. Though no clear clinical evidence links hydrogenated soy oil to toxicity, trans fats have drawn scientific concern due to their impact on cholesterol. They raise LDL and lower HDL, contributing to cardiovascular disease (CVD) risk. A high trans-fat diet also increases lipoprotein(a), a strong CVD risk factor. The American Heart Association recommends limiting intake, and U.S. regulations require labeling of trans fat content. In Africa, reduction technologies are still emerging. While animal studies show adverse effects from severely oxidized fats, such as fatty liver and reproductive issues, humans typically do not consume fats at such extreme oxidation levels (Hajek *et al.*, 2021).

Effects of Processing on Soybean Carbohydrates

Soy products contain carbohydrates, which can lead to Maillard browning. This occurs when amino acids react with reducing sugars, especially at processing temperatures above 150°C. In studies with ruminants, reducing the particle size of soy flours increased the degradability of both crude protein (CP) and nonstructural carbohydrates in the rumen. Conversely, another study found that heat treatment reduced CP degradability but increased the breakdown of nonstructural carbohydrates in soy flour within the rumen. Moisture enhances the impact of heat on starch degradation, and heating has been shown to improve starch digestibility in laboratory tests. Additionally, heating has been reported to increase metabolizable energy and amino acid availability from both full-fat and defatted soybeans in hens (El Hosry *et al.,* 2025).

Effects of Processing on Soybean Minerals

SB processing generally does not lead to significant losses of trace minerals, except for silicon. Silicon tends to bind with soil particles and dissolves in the wash water, leading to its loss. Sodium, potassium, magnesium, and calcium may also be lost if excessive water is used during washing and preparation and then discarded. When SB is concentrated for protein, the levels of iron, zinc, aluminum, strontium, and selenium increase, suggesting these minerals may be closely associated with the protein fraction. Molybdenum, boron, cobalt, manganese, iodine, and barium show variable changes without a consistent pattern. During processing, most SB minerals tend to follow the protein or meal. Some calcium, phosphorus, and magnesium can be extracted with phospholipids and become part of the oil. Minerals like iron and copper are considered contaminants because they are strong peroxidants. These contaminants can originate from the raw beans or from contact with metals during processing (El Hosry *et al.,* 2025).

Effects of Processing on Soybean Omega-3 Fatty Acids

Omega-3 and omega-6 fatty acids, found in nearly equal amounts in soy oil, are bioactive compounds crucial for membrane fluidity, cellular signaling, gene expression, and eicosanoid metabolism. Phytosterols, conjugated linoleic acid (CLA), and carotenoids are also significant bioactive compounds. Soybeans are a rich plant source of omega-3 and omega-6 fatty acids, carotenoids, and phytosterols. Probiotic yogurt, a fermented dairy product made with milk enriched with CLA and concentrated trans vaccenic acid (TVA), was heat-treated at 85°C for 30 minutes without any significant reduction in CLA and TVA levels. However, an experiment replacing milk fat with high amounts of omega-3 fatty acids showed that the process negatively impacted the yogurt's texture, causing increased syneresis and loss of firmness, although it did not affect the typical yogurt flavor and nutritional value. There is a concern about the potential oxidative loss of omega-3 fatty acids during thermal processing and long-term storage of fortified foods (El Hosry *et al.,* 2025).

Effects of Processing on Soybean Vitamins

Tocopherols inhibit singlet-oxygen-mediated oxidation in soybean (SB) oil. Although Vitamin E is stable without oxygen, it degrades in its presence, especially with free radicals. Processing SB into tofu causes a 30–40% Vitamin E loss, though tofu has more tocopherols than whole beans by dry weight. During oil extraction, lipid-soluble vitamins like Vitamin E transfer into the oil, while water-soluble vitamins are lost in discarded liquids. Soy oil contains 9–12 mg/g α-tocopherol, 74–102 mg/g γ-tocopherol, and 24–30 mg/g δ-tocopherol; β-tocopherol is minimal (<3%). Rapid hydration hydrothermal cooking yields soymilk with more thiamine and protein than traditional methods. Traditionally processed SB curd has higher protein and fat but lower carbohydrate and ash. Amino acid profiles also differ between methods. Vitamins K and A remain stable during thermal processing. Overall, vitamin retention varies by processing method, influenced by each vitamin's structure and environmental conditions, making outcomes difficult to generalize (Jha *et al.,* 2022).

Effects of Processing on Soybean Isoflavones

In a study with female participants, it was found that higher intake of dietary fiber and carbohydrates was linked to increased urinary excretion of equol, an isoflavone. The same study revealed that fermenting soy reduced its isoflavone content but enhanced urinary recovery of these compounds, suggesting that fermentation boosts the bioavailability of soy isoflavones. This indicates that soy processing influences isoflavonoid metabolism and should be considered when recommending soy foods for isoflavone intake. Although the ideal isoflavonoid exposure for disease prevention is not yet established, the study noted that urinary excretion of isoflavonoids is consistent at low to moderate levels of soy protein intake, specifically 5-20 grams of soy protein powder per day, which equates to approximately 9-36 mg of isoflavones daily (Hwang *et al.,* 2018).

CONCLUSION

Soybean processing typically begins under gentle conditions, preserving most of its nutritional value. Dehulling may reduce mineral content, and drying at 60–90°C can slightly denature proteins and diminish heat-sensitive amino acids, depending on exposure time. Lipid-protein interactions may also lower the bioavailability of essential nutrients. Moderate heat treatment improves digestibility by inactivating trypsin inhibitors and denaturing globulins, enhancing protein absorption. However, chemical reactions during processing—especially those forming covalent bonds between proteins—can reduce amino acid availability. Excessive heat may trigger denaturation and generate potentially harmful or mutagenic compounds. Hydrogenation transforms unsaturated fatty acids into trans isomers, which are linked to increased cholesterol levels and reduced nutritional quality. Processing affects both the taste and nutritional profile of soy products. To limit adverse effects, practices like minimal washing, fermentation, and brief heating below 100°C are recommended. Nonetheless, high temperatures in soy oil hydrogenation can introduce health risks. Lowering hydrogenation temperatures and modifying catalysts may reduce trans-fat formation and improve consumer health outcomes.

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