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Soybean (*Glycine max* L.) & its health benefits

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Abstract

Soybean contributes to 28% of the world's edible oil, and is second in production of edible oils to palm oil. The soybean is a valuable legume because it does provide all of the essential amino acids for humans; however it is relatively low in the sulfur containing amino acids, cysteine and methionine. It is one of the few legumes that can be consumed as a complete protein. The soybean is comprised of approximately 37-42% protein. The two main proteins of soybean are 11S glycinin, and 7S β-conglycinin, both globular in structure. Glycinins composed of acid/base polypeptide units and contains a higher percentage of sulfur-containing amino acids. The carbohydrate composition of the soybean consists primarily of fiber. The primary non-fiber carbohydrates in soy are the oligosaccharides, raffinose, stachyose and verbiscose. Raffinose is a trisaccharide of galactose, glucose and fructose, bound by 1 to 6 and 1 to 2 glycosidic linkages respectively and stachyose is tetrasaccharide of 2 galactoses, glucose, and fructose bound by 1 to 6, 1 to 6, and 1 to 2 glycosidic linkages respectively. Neither is digested in the small intestines as humans lack the enzyme α galactosidase. Passed into the colon they serve as an energy substrate for colonic bacteria, producing hydrogen and methane, and hence flatulence. Soy research has many exciting advances as breeding and genetic modifications are allowing for higher protein beans and desirable fatty acids profiles for food use and for health. Soybean products are useful not only for the vegetarian, but also for other aspect of diet therapy. As a component of soy, isoflavones potentially have a wide range of positive effects on human health. Their complexity of structure and intestinal metabolism creates difficulties in the interpretation and comparison of experiments, but clearly there are many positive human health effects of isoflavones derived from soy.

Keywords: soyabean, health benefits, diabetes, cancer, kidney disease and heart disease

Introduction

Soybean (*Glycine max* L.) is a species of legume native to East Asia, widely grown for its edible bean which has several uses. This chapter will focuses on soybean nutrition and soy food products, and describe the main bioactive compounds in the soybean and their effects on human and animal health.

History of the Soybean

The soybean plant, Glycine soja (wild) Glycine max (cultivated), has a long history of cultivation with an estimated beginning in China around 1700-1100 years C.E. Soy was introduced to other regions beyond China such as Indonesia, the Philippines, and Japan during the first century C.E. As Europeans traveled to China and Japan, they were introduced to food products made from soybean such as miso and soy sauce, but did not make the connection between these products and the soybean. It was not until later in the 1700's that the soybean was introduced to Europe. The soybean plant was first brought to the U.S. in 1765 by Samuel Bowen. It did not reach immediate success as a cultivated crop in the U.S. Hymowitz provides an excellent summary of soy's rocky road to a widely cultivated crop. Initially, it had early appeal in the late 1800's/early 1900's in the U.S. as a high protein livestock feed. Since, the soybean has become one of the largest crops in the world with global production estimated at 293.97 MMT for 2014/15. Soy foods retail sales in the U.S. alone are estimated at $4.5 billion in 2013. The soybean is now one of the most highly genetically modified plants; in fact genome sequencing for this plant was accomplished before that of corn and cotton. There is an abundance of research on the soybean and how soy affects human and animal nutrition.

Nutritional facts

- **Lipid**

  Soybean contributes to 28% of the world's edible oil, and is second in production of edible oils to palm oil. It should be noted that oils are produced from plant sources for other purposes than food such as detergents, candles, pharmaceuticals, and biofuels. considering these products, soy contributes to half of the world production of oil. Edible oils from soybean are processed to create numerous food products such as salad dressings, margarines, and spreads. Oil comprises of 17-19% of soybean dry weight, of which most is polyunsaturated fatty acids. Fatty acid profile will depend on the genotype, but in general, the majority of fatty acids consist of linoleic acid (53-54%). The oil is obtained from the bean by solvent extraction from the bean pod. The lipid fraction is then processed and refined to remove impurities such as pigments, proteins, carbohydrates, and other chemicals that affect taste and appearance. Within the lipid fraction exists phospholipids (collectively called lecithin) and tocopherols. A degumming process removes phospholipids. The tocopherols act as natural antioxidants, a positive role for soy oil since it is quite susceptible to oxidative rancidity. The lipid content of soybeans in wild types is known for its high unsaturated fatty acid content. Because of the high unsaturated fatty acid content in soy oil, it is considered to have a more beneficial lipid profile desired for human consumption. A higher unsaturated fatty acid intake is associated with lower risk of cardiovascular disease and, α-linolenic acid present in soy oil is a precursor of EPA and DHA, both of which are studied for their proposed benefit for cardiovascular and brain health. One major advance in the production of soy oil has been the use of genetically modified soybeans to alter the fatty acid profile of the oil. High oleic acid soybeans have been genetically designed as a greater percentage of oleic acid can improve the oxidative stability of the oil. DuPont developed a genetically modified high oleic acid soybean in the mid 1990's. Other high oleic acid lines, with greater than 80% to greater than 90% oleic acid (percentage of all fatty acids) were developed and approved for production and commercialization on a limited scale in 1998 and 2002 in the U.S. and Japan respectively. A genome sequencing project, Qualisoy, was developed from the Better Bean Initiative. This program has worked to improve soybean lines with altered fatty acid compositions, protein compositions, and creation of specific varieties for tofu, soy drinks, or natto. Currently there is need to provide a soy oil that provides necessary fatty acid profile for desirable cooking/processing qualities without trans fatty acids in view of the FDA's recent elimination of GRAS status for trans fats. The fatty acid profiles of soybean oils have high 18:2n-6 (~50%) and significant 18:3n-3 (~10%) contents, making the oil susceptible to oxidation. Partial hydrogenation produces trans isomers from the polyunsaturated fatty acids in soybean oil, lowering the total unsaturation and oxidation rates. While trans fatty acids are not found in non-processed soybean oils, trans isomers, mainly positional trans isomers, are formed in partially hydrogenated soybean oils at relatively high levels. Geometrical isomers of 18:2n-6 and 18:3n-3 are found in deodorized oils at low total levels but the relative amount of isomerization of 18:2n-6 and 18:3n-3 can be significant, depending on the time-temperature of deodorization. There are genetically modified low linolenic acid soybeans that have no trans fats. Fully hydrogenated soybean oil interesterified with soy oil blends have also been studied to create more stable oils. Genetically modified high stearic acid soy oil may be a product in the future that allows for physical properties of saturated fats but without the negative effects on serum lipid profiles.

- **Protein**

The soybean is a valuable legume because it does provide all of the essential amino acids for humans; however it is relatively low in the sulfur containing amino acids, cysteine and methionine. It is one of the few legumes that can be consumed as a complete protein. The soybean is comprised of approximately 37-42% protein. The two main proteins of soybean are 11S glycinin, and 7S β-conglycinin, both globular in structure. Glycinins composed of acid/base polypeptide units and contains a higher percentage of sulfur-containing amino acids. For this reason, a higher ratio of glycinin to β-conglycinin improves the protein quality of soy. β-conglycinins, a glycoprotein that has 3 homologous subunits, α, α', and β. Medic and Wang provide in depth reviews of the structure of these proteins. Nitrogen and sulfur fertilization can affect accumulation of one or the other of these proteins. Soy protein is also responsible for initiating an allergenic response in susceptible individuals. Indeed, soy is one of the 8 foods responsible for causing the majority of food allergies. Both glycinin and β-conglycinin are believed to be responsible as allergens. There are also other proteins, such as the protease inhibitors and whey fractions, within the soybean that cause allergenic responses, and there is the potential to breed and genetically modify the soybean to decrease allergenicity of soybean for human consumption. Other proteins within the soybean are anti nutritional factors. Lectins are hemagglutinins; when consumed raw, lectins often cause alterations in small bowel histology and affect growth of animal.

- **Carbohydrates**

The carbohydrate composition of the soybean consists primarily of fiber. The primary non-fiber carbohydrates in soy are the oligosaccharides, raffinose, stachyose and verbiscose. Raffinose is a trisaccharide of galactose, glucose and fructose, bound by 1 to 6 and 1 to 2 glycosidic linkages respectively and stachyose is tetrasaccharide of 2 galactoses, glucose, and fructose bound by 1 to 6, 1 to 6, and 1 to 2 glycosidic linkages respectively. Neither is digested in the small intestines as humans lack the enzyme α galactosidase. Passed into the colon they serve as an energy substrate for colonic bacteria, producing hydrogen and methane, and hence flatulence. While discomforting, this role may allow them to serve as prebiotics for colonic bacteria, reducing the risk of colon cancer. Interestingly, raffinose and stachyose and other oligosaccharides in plants are believed to play a role in is the other nonstructural carbohydrate that is present to a relatively significant degree. The presence of sucrose provides some sweetness to processed soy products. The content of these starches vary depending on genotype from 5.72-7.00% soluble sugars and altering the oligosaccharides content is possible, but currently, cooking methodology and fermentation appear to best modulate oligosaccharides in soybean for human consumption.

- **Functional food components**

Isoflavones are found in significant concentration in the soybean, composing 0.05-0.5% of dry weight. This has become an area of great interest due to correlations of isoflavones with health benefit which will be reviewed below. Isoflavones are a subgroup of polyphenols; the two major isoflavones found in soy are genistin and daidzin (aglycone forms are genistein and daidzein respectively). Both have glucose moieties bound to them; during digestion glucosidase enzymes remove the glucose leaving aglycones which are absorbed into the lymphatic system. Isoflavone content of the soybean varies according to soybean genotype and environmental conditions during growth of the plant. Because genotype can influence the type and concentration of isoflavones, this is also an area of research in growing conditions for, breeding, and genetic engineering of the plant to produce high concentrations of isoflavones in the soybean. Saponins are triterpenoidal compounds that form water-soluble complexes with cholesterol, preventing its absorption. Soybean is a good source of this group of compounds also. Saponin content varies largely depending on the genotype of the soybean from 11.0- 35.6 mg/g seed. Phytic acid is considered an anti nutritonal factor because it binds to important minerals, including calcium, iron, zinc, and copper, inhibiting their absorption. Soybean contains 1-1.5% (dry weight) phytic acid and the majority of the phosphorous in soy is bound to phytic acid.

Incorporating Soy in the Diet

To meet their daily requirements of calcium, vitamin D, vitamin B12, and zinc, vegans should emphasize consumption of soy products as tempeh, tofu, roasted soy nuts, edamame, calcium-fortified soymilk and soy-based meat analogs. Some examples of meals and snacks that offer complementary proteins for them include cereal with soymilk, rice pudding made with soymilk, textured soy protein taco with a corn tortilla, soy hot dog in a bun, and tofu salad instead of egg salad. Some of the new soy products include soy nut butter, soy burgers, ground taco-burrito filler, sweet Italian sausage, soy sausage links, tofu cream cheese, veggie sour cream, soy yogurt, and soy ice cream. Soft or silken tofu can be blended and flavored to make puddings smoothies, sauces, salad dressings and dips, while extra-firm tofu can be used in stir-fries or grilling. Up to a quarter of flour can easily be replaced with soy flour in recipes of muffins, bread, pancakes, biscuits etc. To help vegan infants meet their protein needs, one can easily use well-mashed tofu and soy yogurt. However, soy should not be incorporated in the diet of an infant if allergy to soy is suspected.

The Use of Soy in Diet Therapy

- **Prevention of Chronic Kidney Disease**
  Consumption of a vegetarian diet that includes soy protein reduces urinary protein excretion in nephrotic patients and those with advanced renal disease. Such diets that include soy protein also lower phosphorus intake and urinary phosphate excretion, which is advantageous for pre-dialysis and dialysis patients. Soy-based vegan diets appear to be nutritionally adequate for people with chronic kidney disease and are likely to slow progression of kidney disease. Vegetarian diets may be especially important as kidney function declines with age.

- **Against Cardiovascular Disease**
  Factors that increase the risk for heart disease include consumption of trans fats, high Glycemic Index foods, and a Western dietary pattern. On the other hand, the factors that reduce the risk for heart disease include consumption of monounsaturated fatty acids, Mediterranean and prudent dietary patterns, nuts, avocados, soy foods, and high intake of anti-oxidants in fruits and vegetables. One may note that the fat content of soymilk is similar to that of reduced fat cow's milk. Sacks (2006) provided an excellent review of research regarding soy protein and soy isoflavones to cardiovascular disease. Soy isoflavones have been postulated to play a role in reducing LDL cholesterol levels and in reducing the susceptibility of LDL to oxidation. A near vegan diet high in phytosterols, viscous fiber, nuts, and soy protein has been shown to be as effective as a low saturated fat diet and a statin for lowering serum LDL-cholesterol levels.

- **Prevention of Diabetes Mellitus**
  Vegetarians are less likely to develop Type 2 Diabetes due to the following reasons: higher fiber and lower saturated fat intake, a higher intake of lower-Glycemic Index foods such as nuts, legumes, fruits and vegetables, and lower rates of hypertension that prevent diabetic complications. Low-protein diets do not adversely affect kidney function. Soy protein may favorably affect renal function in diabetics. In a study conducted by Vilegas, the risk of type 2 diabetes was 38% and 47% lower for those consuming a high intake of total legumes and soybeans, respectively, compared to their low intake.

- **Prevention of Cancer**
  Soy isoflavones and soy foods have been shown to possess anticancer properties. A meta-analysis of eight studies (one cohort, and seven case controls) conducted in high-soy-consuming Asians showed a significant trend of increasing soy food intake with decreasing risk of breast cancer. In contrast, soy intake was unrelated to breast cancer risk in studies conducted in 11 low-soy-consuming Western populations. One of the ways in which isoflavone genistein slows the growth of cancer cells is by inhibiting several enzymes involved in signal transduction, including tyrosine protein kinases, MAP kinase, and ribosomal S6 kinase. Genistein also inhibits the activity of DNA topoisomerase II. Peterson *et al* reported that genistein increased the in-vitro concentrations of Transforming Growth Factor β (TGFβ). This last finding may be particularly important given the role that TGFβ may have in inhibiting the growth of cancer cells. Besides isoflavones as daidzein and genistein, other phytochemicals present in soybeans such as phytosterols, phytates, saponins, protease inhibitors, and a variety of phenolic acids have also been shown to demonstrate ant carcinogenic activity. Studies have reported that consumption of soy products in childhood is associated with a lower risk of breast cancer in adulthood. However, it is still controversial if soy should be regarded as a cancer protective agent, because not all research supports the protective value of soy towards breast cancer.

Soyabean and Isoflavones

Isoflavones are a class of polyphenol compounds that have reported biological activities and antioxidant properties. They are called isoflavones because the B ring is attached to the adjacent carbon from a typical flavone structure. Although the flavones are widespread in plants, isoflavones are found in few plants, mainly in legumes such as soy (Glycine max) and chickpea (Cicer arietinum L), and in the tuber-producing vine, kudzu (Pueraria lobata). A great deal of attention has been focused on isoflavones because they have potential effects on cancer, cardiovascular diseases, osteoporosis and symptoms of menopause. Postmenopausal women have sharply increased incidences of hypercholesterolemia, coronary heart disease and risk of osteoporosis. Several excellent reviews have been published on isoflavones recently so this manuscript will focus on some of the more recent information. Isoflavones are one of the main chemical classes that have been found to have estrogenic activity that are derived from plants. The estrogenic activity arises because structural similarity allows them to bind to estrogen receptors, resulting in antagonistic, agonistic or mixed effects at the receptor level. Because of this, they have been called phytoestrogens and much of the reported bioactivity focuses on their estrogenic or antagonistic effects. Soy isoflavones exist as three main aglycone forms but also as glucoside forms (the O-glucosides of aglucones diadzein, genistein and glycitenin are named diadzin, genistin, and glycitin).

Analysis of isoflavones is complicated by the numerous possible forms present and because processing can affect levels and compositions of individual compounds. Additionally, intestinal micro flora metabolize isoflavones to forms equol, an isoflavandiol that may also be absorbed, have greater estrogenic activity and longer half life in humans. Because intestinal micro flora differ among people, some are able to produce much greater amounts of equol than others, making human experimentation challenging. Soy derived isoflavones have been shown to have a wide range of effects on human health, including ameliorating symptoms of menopause, osteoporosis, cancer and heart disease. Reported positive effects are not limited to women; as a dihydrotestosterone blocker, equal may have positive effects on male pattern baldness as well as lowering incidence of prostate cancer. One of the difficulties in the interpretation of studies on soy isoflavones and health is that different forms of soy or soy extracts have different levels of concentration and doses. Processing and fermentation of soy products reduce the isoflavone levels significantly. It is important to measure all of the isoflavone forms in foods or supplements. Fermentation results in more aglycone forms as a result of hydrolysis during fermentation, and thermal processing by extrusion results in more acetyl forms compared to malonyl forms. A randomized double-blind study (n experimental = 30, n control = 31) on the supplementation of diets of post-menopausal women with soy providing 54 mg of isoflavones per day was conducted over 8 weeks. The study focused on blood pressure, circulating hormonal levels and symptoms as measured using the Blatt-Kupperman index (a measure of menopausal symptoms including depression, fatigue, hot flashes, joint or muscle pain, paresthia, insomnia, mood swings, vertigo, headache, palpitation). No significant change was observed in diastolic or systolic blood pressure in the isoflavone treatment group, but there was a significant improvement in menopause symptom severity and intensity, as determined using the Blatt-Kupperman index. This is in agreement with other studies that have shown isoflavones can help reduce symptoms of menopause. Levels of the circulating hormones, follicular stimulating hormone and luteinizing hormone, decreased after isoflavone supplementation, but estradiol levels increased. The supplementation of soy isoflavones (40-80 mg/ day) was studied for hot flashes and night sweats in African postmenopausal women. Although this was not a double blind, placebo controlled study, results indicated that the incidence of night sweats and hot flashes decreased significantly after 4 months. These studies underline the positive effects of soy isoflavones on menopause symptoms. Soy isoflavones are known to have antioxidant effects in vivo and in vitro and the impact of soy isoflavone extract supplementation on hypoxia and fatigue was studied in mice. Soy isoflavones improved serum lactate and urea levels and extended survival under hypoxia and sodium nitrite toxicity conditions. The supplementation levels were quite high (200-600 mg/kg) and the isoflavone extract was only characterized by genistein and diadzein concentrations; the other isoflavone/forms known to exist in soy were not reported. Isoflavone extracts are not all equal, and some commercial isoflavone extracts have been reported to contain mycotoxins and pesticides. Nonetheless, these contaminants are likely found only in low concentrations and the main problem with interpretation across experiments is the incomplete characterization of the isoflavone profiles of samples provided. One of the results of the estrogen deficiency that occurs after menopause is increased oxidative stress and insulin resistance. In ovariectomized rats, supplementation with 150 mg soy isoflavones/ day for 12 weeks resulted in lower oxidative stress and improved measures of glucose intolerance and insulin resistance. Soy isoflavones also improved symptoms in rats fed a high-fat diet, which exacerbates metabolic problems associated with estrogen loss. Soy milk consumption was studied as a means of reducing markers of inflammation and oxidative stress in women with rheumatoid arthritis in a randomized, cross-over trial. Treatment phases were 4 weeks, with a 2 weeks washout and an additional 4 weeks on the crossed diet. Soy milk consumption resulted in lower levels of serum TNF-α (Tumor Necrosis Factor Alpha) and CRP (C-reactive protein), indicating reduced inflammation, although there was no difference in blood malonaldehyde (a measure of polyunsaturated fatty acid oxidation) levels after soy milk consumption. Asthma is a complex disease and some studies have shown a potentially positive effect of soy isoflavones on severity of symptoms. A randomized, double-blind, placebo-controlled study was conducted of soy isoflavone supplementation in patients with poorly-controlled asthma who were taking a controller medication. The isoflavone pill supplements contained 49 mg total isoflavones, with around 32 mg as aglycone form. The concentration of genistein in plasma increased significantly (4.87 ng/ml compared to 37.67 ng/ml) after isoflavone consumption, but there were no significant differences in measures of lung function or clinical measures of disease.

Conclusion

Soy research has many exciting advances as breeding and genetic modifications are allowing for higher protein beans and desirable fatty acids profiles for food use and for health. Soybean products are useful not only for the vegetarian, but also for other aspect of diet therapy. As a component of soy, isoflavones potentially have a wide range of positive effects on human health. Their complexity of structure and intestinal metabolism creates difficulties in the interpretation and comparison of experiments, but clearly there are many positive human health effects of isoflavones derived from soy.

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