Phytochemicals in soybeans
Their potential health benefits

Soybeans have been a valuable resource for mankind by providing excellent protein and other nutrients. There is strong evidence that dietary soy protein can lower serum cholesterol levels, which in turn reduces the risk of heart disease. There also is increasingly convincing evidence that consumption of soy foods can prevent various cancers.

Research has credited the phytochemicals in soybeans for these beneficial effects. Literally, phytochemicals are “chemicals from plants.” However, phytochemicals are defined by researchers as minor non-nutritive components from plants. Soybeans have many unique phytochemicals including isoflavones, saponins, phytates, phytosterols, phenolic acids, and trypsin inhibitors. All of these compounds have been cited as important in prevention of degenerative conditions such as heart diseases and cancers. For a long time, phytochemicals have been regarded as irrelevant to nutrition, since they neither yield energy nor function as vitamins. Furthermore, many phytochemicals have been considered antinutrients in traditional nutritional theory. However, antinutrients may play critical roles in prevention of diseases that result from over-nutrition.

**Soy isoflavones**

Isoflavones are a class of phenolic compounds, including daidzein, glycitein, and genistein (Figure 1). Isoflavones exist in soybeans either as glucosides or in free form (aglucones). The glucosides of daidzein, glycitein, and genistein are called daidzin, glycitin

**Figure 1. Structures of soy isoflavone aglucones**

itin, and genistin, respectively. Two derivatives for each glucoside also exist in soybeans: 6'-O-acetyl-daidzin, -glycitin, and -genistin; and 6'-O-malonyl-daidzin, -glycitin, and -genistin. These isoflavone compounds, previously considered antinutrients, play such significant roles in prevention of heart diseases and cancers that they may come to be regarded as the vitamins of the 21st century.

The risk for breast cancer among native Chinese is about 10% of that of North Americans. The risk for prostate cancer of the Chinese population is only 2% of that of the North Americans. Although many factors contribute to these differences, soy consumption could be a major factor. A study on Japanese and Finnish women showed a strong correlation between high urinary isoflavone content and a low breast cancer rate. Among Asian women, high tofu consumption was found to be associated with a reduced risk for breast cancer. In vitro studies have shown that genistein has inhibitory effects on many cancer cell lines, including breast, prostate, thyroid, and gastrointestinal. The anticarcinogenic properties of genistein also were demonstrated in rat breast cancer models.

The exact mechanism by which isoflavones act as anticarcinogens is not known. However, there are several proposed mechanisms. First, some isoflavones, especially genistein, can compete for estrogen receptors with estrogen, the female sex hormone. Therefore, isoflavones function as antiestrogens and are protective against hormone-related cancers. Second, isoflavones inhibit some of the enzymes, such as tyrosine kinase, associated with carcinogenesis. Third, some isoflavones are found to inhibit angiogenesis, which is essential for the development of tumors.

It has been well-established that soy protein products are hypcholesterolemic. Isoflavones are thought to be at least partially responsible for this property. Reduced cholesterol levels in turn can reduce the risk of cardiovascular disease for individuals who consume soy ingredients and soy foods. Isoflavones, being potent antioxidants, also may reduce atherosclerosis by inhibiting oxidation of low-density lipoprotein (LDL) cholesterol. In addition, the weak estrogenic properties of isoflavones also could protect postmenopausal women against heart diseases. Isoflavones have been studied for their other potential benefits with regard to bone health and diabetes.

The concentration of isoflavones in soy foods and soy ingredients varies dramatically. First, the genetics of soybean cultivars and the environment where the soybeans are raised have a significant effect on the quantity and type of isoflavones in the soybeans. However, there has been no conclusion as to which environmental factors promote which isoflavones. Second, processing techniques also will affect the concentration of isoflavones. A study on the effects of processing on isoflavones during preparation of soy

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protein isolates revealed that only 23% of the total isoflavones in soy flour remained after the soy flour had been processed to yield soy protein isolates. The washing step caused the greatest loss among the processing steps. New processing technologies or modifications of existing processes are needed to minimize the loss of isoflavones during processing.

**Saponins**

Saponins are a group of glycosides of triterpenoids or steroids. Soybeans are a major dietary source for saponins. Soyasaponins are classified into Groups A, B, and E. As shown in Figure 2, Group A soyasaponins, known as bis-desmosides, contain two ether-linked sugar chains attached to C-3 and C-22. Groups B and E, known as mono-desmosides, contain sugars attached to C-3 alone. There are three predominant forms in raw soybean seeds: soyasaponin αg, soyasaponin βg, and soyasaponin βa, in concentrations ranging from 1 to 3 mg/g. The saponin compound is amphiphilic, the triterpene or steroid portion is hydrophobic, and the sugar portion is hydrophilic. These surface characteristics give saponins their biological activities, including hemolytic, hypocholesterolemic, immunostimulatory, and antitumor properties.

Saponins are hemolytic due to their interactions with cell membranes. For this reason, they are considered anti-nutrients and toxins, although the hemolytic properties of saponins vary according to their specific structures. Some saponins are extremely toxic to fish and other cold-blooded animals, but saponins administered orally to mammals seem to have no toxic effects. Nevertheless, toxicity should be considered when the potential health benefits are explored.

The hypocholesterolemic property of saponins is the major mechanism for their preventive effects against cardiovascular diseases. Dietary saponins can lower plasma cholesterol directly by inhibition of cholesterol absorption or indirectly by inhibition of bile acid reabsorption, thereby increasing fecal excretion of bile acids.

The anticarcinogenic property of saponins has been studied using *in vitro* and *in vivo* studies. In one study, soyasaponins were shown to have dose-dependent growth inhibitory effects against human colon carcinoma (HCT-15) cells. The same researchers later investigated the effects of soybean saponins on colon cancer in the mouse. Soyasaponins at 3% by weight of the diet suppressed azoxymethane-induced mouse colon carcinogenesis. Saponins may function as anticarcinogens in three modes. First, saponins may function directly as cytotoxins to cancer cells. Second, saponins may alter the metabolism of bile acids and reduce production of secondary bile acids and therefore reduce the risk of colon cancer. Third, saponins may function as...
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free-radical scavengers. Due to their relatively poor absorption, saponins are believed to affect only colon cancer risk. However, they might indirectly affect other forms of cancers by reducing serum cholesterol and enhancing immune functions.

Some nonsoy saponins—Formosin-C from a Chinese herbal drug and ginsenoside from ginseng—have been shown to have immune-stimulating effects. It is not known if soyasaponins have similar effects.

Unheated and heated full-fat flours contain approximately the same levels of saponins, indicating soybean saponins are heat-stable. Saponins lend to remain with the protein products derived from soybeans during processing. Fermentation results in some degradation of saponins. Details on the mass balance of saponins during processing of soy products are unknown.

Phytic acid

Phytic acid (myo-inositol 1,2,3,4,5,6-hexakis-dihydrogen phosphate) (Figure 3) is a storage form of phosphorus in plant seeds. Its concentrations in soybeans and in soy products are high (about 1–2%). It has been viewed as an antinutritional factor due to its ability to chelate minerals. It also functions as an antinutrient by binding protein and starch, reducing their digestibility. These properties could be considered as desirable in prevention of cancers, cardiovascular diseases, and diabetes.

A number of in vitro and animal studies have demonstrated potential preventive effects of phytic acid against cancers in colon, mammary glands, and other tissues. The addition of 1% phytic acid to the drinking water of rats one to two weeks prior to administration of azoxymethane, a carcinogen, and up to 12 months afterward significantly decreased tumor size and number. In a mammary cancer study, addition of 2% phytic acid to the diet after administration of the carcinogen dimethylbenz(a)anthracene (DMBA) in rats significantly increased the number of survivors and decreased the tumor size.

The binding of phytic acid with starch, proteins, and minerals might be its major mechanism as an anticarcinogen. Fermentation of unabsorbed starch due to phytic acid produces short-chain fatty acids. This would cause a low pH environment in the colon, which in turn would provide protection against colon cancer by insolubilizing bile acids and neutralizing ammonia. Binding of zinc by phytic acid also may be anticarcinogenic, as zinc is essential during DNA synthesis. Phytic acid also functions as an antioxidant by chelating the prooxidant Fe$^{3+}$ and reducing DNA damage by free radicals.

The potential preventive effect of phytic acid against cardiovascular diseases is likely due to its hypolipidemic and hypocholesterolemic properties. Phytic acid provides a clear benefit for people with diabetes by delaying glucose release from starch. Long-term exposure to phytic acid also may be beneficial in prevention of diabetes by reducing peak glucose concentration and preventing development of tissue resistance to insulin.

Soy protein products (flours, concentrates, and isolates) contain 1–2% phytic acid. The effects on phytic acid content of growing conditions of soybean crops and of processing conditions of soy products need to be systematically studied.

Phytosterols

The phytosterols comprise a number of compounds structurally related to cholesterol. β-Sitosterol, campesterol, and stigmasterol are three major phytosterols in soybeans. Their structures and that of cholesterol are shown in Figure 4. The total phytosterol content of soybeans is 0.3 to 0.6 mg/g.
Figure 5. Amino acid sequences of Kunitz and Bowman-Birk trypsin inhibitors

Although phytosterols are structurally related to cholesterol, they have many "anticholesterol" properties, which have been demonstrated in many animal and human studies. In *vitro* and animal studies also have demonstrated anticarcinogenic properties of phytosterols. Phytosterols are also a feedstock for the manufacture of pharmaceutical steroids.

By the early 1950s, the hypocholesterolemic effect of phytosterols in chicks had been demonstrated. This effect was confirmed in humans by a number of studies. The hypocholesterolemic effect most likely is due to decreased cholesterol absorption. Phytosterols inhibit the formation of bile-cholesterol micelles and compete for the enzymes required for cholesterol uptake. Although only a minimal amount of phytosterols (5%) is absorbed by humans, the absorbed phytosterol may adversely affect cholesterol synthesis.

Phytosterols have been shown to be anticarcinogenic in animal models of colon cancer. This effect is related to the hypocholesterolemic properties of phytosterols. Low cholesterol levels could indirectly lower colon cancer risk. More importantly, phytosterols competitively inhibit cholesterol dehydrogenase and other bacterial enzymes in the colon and therefore reduce the production of the secondary biles that may cause colon cancer.

It is known that refining soybean oil is detrimental to the phytosterol content. However, the detailed mass balance is not understood.

**Trypsin inhibitors**

Trypsin inhibitors are protein molecules that bind with trypsins and interfere with protein hydrolysis during digestion. Kunitz and Bowman-Birk are the two major trypsin
inhibitors in soybeans (Figure 5). They are partially responsible for low protein digestibility of raw soybeans. The Bowman-Birk inhibitor (BBI) has 71 amino acids with seven disulfide bonds and two binding sites: a trypsin-reactive site (Lys 16 and Ser 17) and a chymotrypsin-reactive site (Leu 43 and Ser 44). The Kunitz inhibitor, which has 181 amino acids, possesses only two disulfide bonds and binds stoichiometrically to trypsin and inhibits only trypsin. The Kunitz inhibitor is thermally unstable and is destroyed during most processing procedures. However, Bowman-Birk is relatively thermal stable and can survive normal thermal treatment. Nevertheless, heat treatment has been the most effective way of inactivating trypsin inhibitors and improving the soy protein digestibility.

Besides causing low protein digestibility, trypsin inhibitors have been shown to cause pancreatic enlargement in rats. Physiologically, when trypsin inhibitors from soybeans bind with trypsin then the pancreas responds by producing more enzyme via increased activity of the hormone cholecystokinin. However, this effect has not been observed in guinea pigs, calves, pigs, or monkeys. Recently, there has been renewed interest in trypsin inhibitors due to their reported anticarcinogenic properties. BBI has been shown to be very effective in preventing carcinogenesis in the liver, lung, and gastrointestinal in mouse models. The mechanism of prevention is not clear, however, it has been suggested that protease inhibitors suppress both initiation and promotion stages of carcinogenesis.

**Phenolic acids**

Phenolic acids are another class of complicated phytochemicals. Syringaldehyde, o-coumaric acid, and gentisic acid (Figure 6) are the three major ones in soybeans. Many in vitro and in vivo studies have demonstrated anticarcinogenic properties of phenolic acids, including ferulic acid, chlorogenic acid, caffeic acid, and ellagic acid. However, no data are available on the three major phenolic acids in soybeans. Knowledge on analysis, presence, and processing of phenolic acids is also very limited.

**Bibliography and Journals**

*Journal of Agricultural Food Chemistry*


*Journal of Nutrition*


*Journal of the American Oil Chemists' Society*


**Other**


**Figure 6. Structures of three major phenolic acids in soybeans**