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Revisión

Soybean, a promising health source

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Abstract

Health properties and uses of soybean, as well as the different chemical and botanical characteristics of this legume are shown in this review. Soybean represents an excellent source of high quality protein, it has a low content in saturated fat, it contains a great amount of dietary fibre and its isoflavone content makes it singular among other legumes.

Many researches have been carried out into the benefits of legumes: chickpeas, beans, lentils and soy, among others, but characterization and positive health effects of soybeans have been recently studied. The interest in this legume has increased because of its functional components. Most of the studies have been focused on soybean protein as a possible source of prevention against cardiovascular disease. This positive effect may be due to a decrease in serum cholesterol concentrations. In addition, there are many studies on isoflavones, non-nutritive substances, associated with prevention and treatment of different chronic diseases. Moreover, some studies have shown the health properties of soy dietary fibre. Therefore, it would be interesting to consider the replacement of animal based foods for soybean foods in order to obtain some nutritional benefits.

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Key words: *Soybean. Diabetes. Cholesterol. Cancer. Menopause. Osteoporosis.*

SOJA, UNA PROMETEDORA FUENTE DE SALUD

Resumen

Esta revisión aborda los diferentes usos y propiedades beneficiosas para la salud de la soja, así como, las distintas características químicas y botánicas de esta legumbre. Existen trabajos científicos que aseguran su efecto protector en diferentes enfermedades, sin embargo, otros lo ponen en duda. De todos modos la soja es una excelente fuente de proteína de alto valor biológico, presenta baja cantidad de grasa saturada, contiene gran cantidad de fibra alimentaria y es única entre las legumbres por su contenido en isoflavonas.

Existe mucha información acerca del papel beneficioso de la ingesta de legumbres: garbanzos, judías, lentejas y soja, entre otras. La caracterización y los efectos beneficiosos en salud de la soja han sido recientemente estudiados, ya que el descubrimiento de sus componentes funcionales y la controversia que ello suscita ha aumentado el interés en esta legumbre. La mayor parte de estos estudios se centran en la proteína de soja como posible fuente de prevención de las enfermedades cardiovasculares. Este efecto positivo puede ser debido a una disminución del colesterol sanguíneo. Además existen muchos estudios acerca de las isoflavonas, sustancias no nutritivas, asociadas a la prevención y tratamiento de diferentes enfermedades crónicas. También algunos estudios han mostrado el papel beneficioso de la fibra alimentaria de soja. De manera que se podrían considerar las interesantes ventajas nutricionales que proporcionaría la disminución de algunos alimentos de origen animal y la ingesta, en su caso, de alimentos derivados de la soja.

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Palabras clave: *Soja. Diabetes. Colesterol. Cáncer. Menopausia. Osteoporosis.*

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Introduction

Botanically, soybean belongs to the order *Rosaceae,* family *Leguminosae* or *Papillonaceae* or *Fabaceae,* subfamily *Papilionoidae,* the genus *Glycine* and the cultivar Glycine max.

In October 26th, 1999, the Food and Drug Administration (FDA) in USA approved a health claim based on the role of soybean protein in reducing the risk of coronary heart disease. This claim establishes that soybean protein included in a diet low in saturated fat and cholesterol may reduce the risk of coronary heart disease. The available researches showed that a frequent soybean protein consumption lowers the cholesterol levels.[1,2]

The results from recent researches suggest that soybean dietary fibre plays a role in the reduction of cholesterol levels in some hyperlipidemic individuals and has a major protective effect on cardiovascular disease.[3-7] Moreover, it improves the glucose tolerance in some diabetic patients;[8-10] it increases the wet faecal weight and reduces the caloric density in some foods.[11] Dietary fibre seems also to have a positive effect on diarrhoea and constipation and as a therapy of irritable bowel syndrome;[12] it has anti- inflammatory and anti-carcinogenic effects on digestive system.[13]

Origin and composition

It is widely believed that the origins of soybean are in China, probably in the north and central regions, 4,000-5,000 years ago. Soybean was introduced in Europe about 1712 by a German botanist, Engelbert Kaempfer. Later Carl von Linné, gave soybeans a genetic name, Glycine max. However, due to the poor climate and soil conditions, soybean production has been limited in Europe.[11,14]

Soybean is a singular food because of its rich nutrient content. Soybean contains vegetable protein, oligosaccharides, dietary fibre, phytochemicals (especially isoflavones), and minerals[4,8,11] (table I).

Protein

Soybean is a protein source. The protein content of most beans averages 20-25%, whereas the protein content of soybean is about 40%.[11] Soybean protein is low in sulphur amino acids, being methionine the most significant limiting amino acid, followed by cystine and threonine.[15] But this difference is actually not really high and soybean protein foods are equivalent in quality to animal protein[4]. Moreover, soybean protein contains sufficient lysine, which is deficient in most cereal proteins. Therefore, soybean amino acid profile is complementary to cereal amino acid profile. Thereby, legumes may be used to fortify cereals (table II).

There are other natural components present in soybeans such as trypsin inhibitors, fenolics and phytic acid, which reduce protein quality.[11]

Table I
Nutrition profile of soybeans expressed per 100 g DM

Composition	*Soybean beans*
Complex carbohydrates (g)	21
Simple carbohydrate (g)	9
Stachyose (mg)	3,300
Raffinose (mg)	1,600
Protein (g)	36
Total fat (g)	19
Saturated fat (g)	2.8
Monounsaturated fat (g)	4.4
Polyunsaturated fat (g)	11.2
Insoluble fibre (g)	10
Soluble fibre (g)	7
Calcium (mg)	276
Magnesium (mg)	280
Potassium (mg)	1,797
Iron (mg)	16
Zinc (mg)	4.8

DM: dry matter.

Fat

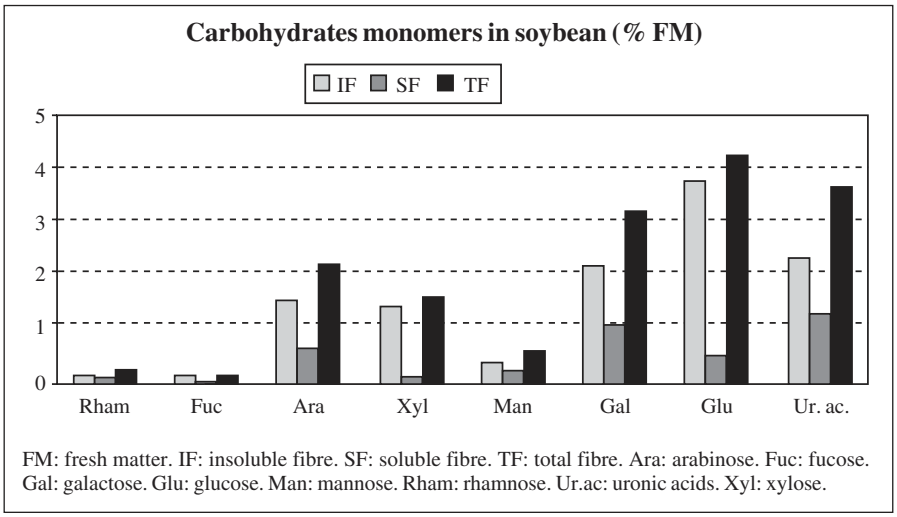
Soybeans normally contain 18-22% oil. Fat fraction contains mainly triglycerides that make up 99% of soybean fat. Minor components include phospholipids, unsaponifiable matter (tocopherols, phytosterols, and carbohydrates), and free fatty acids.[11] Most beans are very low in fat, but soybeans are an exception because their fat content is the highest among the beans, containing 47% of energy from fat.[8]

Soybean fat stands out for its high content of the polyunsaturated fatty acids, linoleic (C18: 2) and linolenic (C18: 3) acids. It also contains considerable

Table II
Amino acid composition of soybean seed (Liu, 1997b)

Amino Acid	*mg/g Protein*
Arginine	77.16
Alanine	40.23
Aspartic acid	68.86
Cystine	25.00
Glutamic acid	190.16
Glycine	36.72
Histidine	34.38
4-Hydroxiproline	1.40
Isoleucine	51.58
Leucine	81.69
Lysine	68.37
Methionine	10.70
Phenylalanine	56.29
Proline	52.91
Serine	54.05
Threonine	41.94
Tryptophan	12.73
Tyrosine	41.55
Valine	41.55

DM: dry matter.



FM: fresh matter. IF: insoluble fibre. SF: soluble fibre. TF: total fibre. Ara: arabinose. Fuc: fucose. Gal: galactose. Glu: glucose. Man: mannose. Rham: rhamnose. Ur.ac: uronic acids. Xyl: xylose.

Fig. 1.—The types and levels of carbohydrates monomers in soybean (% FM) (Redondo et al., 2007).

amounts of another unsaturated fatty acids, oleic acid (C18: 1) and moderate amounts of the saturated fatty acids, palmitic acid (C16: 0) and stearic acid (C18: 0). The predominant fatty acid is linoleic acid, comprising approximately 53% of the total fatty acid content of soybean.[15] It is also remarkable linolenic acid content is 7-8% approximately. There are few good sources of ω-3 fatty acids such as linolenic acid. Available data suggest that many people have a diet poor in linolenic acid, so soybean could be a good source to increase the linolenic acid intake.

The term lecithin generally refers to the entire phospholipid fraction. Soybean lecithin is widely used in many industries because of its functional properties such as emulsifying, wetting, colloidal, and antioxidant properties. It also exerts physiological effects on human beings and animals.[11]

Carbohydrates

Soybeans contain about 35% carbohydrates. Therefore, they are the second largest components in soybeans. Soybean meal contains 1% of starch.[16,17] Cell wall structural components are non-starch polysaccharides (NSP) and cover a large variety of polysaccharides molecules excluding α-glucans (starch). NSP fraction is divided in three groups: cellulose, non-cellulosic polymers (hemicelluloses) and pectic polysaccharides.

Cell wall material contains 92% of the polysaccharides present in soybean. The major constituent sugars in these polysaccharides are arabinose, galactose, uronic acids and glucose (cellulose)[18] (fig. 1). Some structures of these polysaccharides have been studied, such as arabinogalactans.[16,17,19] They occur in two distinct types. In grain legumes, it appears as Type I[16,17,20] (fig. 2).

Soybean soluble carbohydrates contain trace amounts of monosaccharides, such as glucose and arabinose, and measurable amounts of di- and oligosaccharides, with sucrose ranging from 2.5-8.2%, raffinose 0.1-0.9%, and stachyose 1.4-4.1%.[11,17,21,22] Raffinose and stachyose have been studied because their presence has been linked to flatulence and abdominal discomfort,[11] but they can be considered prebiotics because they promote the growth of Bifidobacterium population.[22,23] There are different studies showing their role as functional food components.[24]

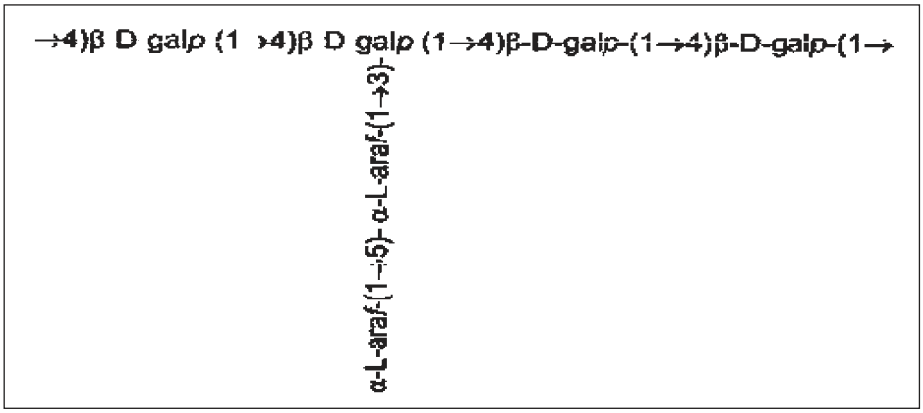


Fig. 2.—Proposed structure of type I arabinogalactan (Van de Vis, 1994).

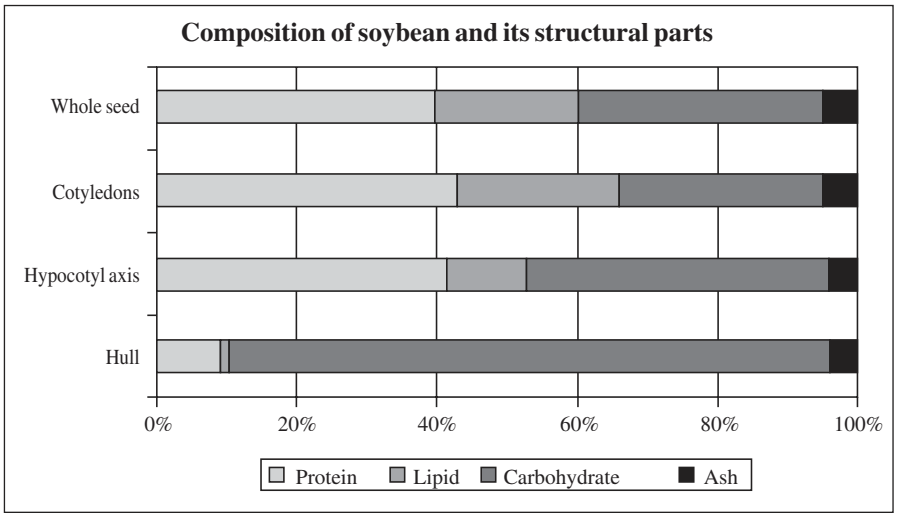


Fig. 3.—Composition of soybeans and their structural parts (% DM).

The seed coat, also known as soybean hull, constitutes the 8% of the whole soybean, containing about 86% complex carbohydrates[11] (fig. 3).

Isoflavones

Isoflavones belong to a group denominated phytochemicals. They are non-nutritive substances that possess health protective benefits. They have been associated with prevention and treatment of chronic diseases such as heart disease, cancer, diabetes, and hypertension as well as other clinical pathologies.[8,25]

Isoflavones are a subclass of flavonoids. The basic structure of flavonoid compounds is the flavone nucleus, which has two benzene rings (A and B) linked with heterocyclic pyrane (fig. 4). Genistein and daidzein are the primary isoflavones in soybean.[15]

Isoflavones are mainly in the form of glycosides in vegetables; they are high polar (water-soluble) compounds. In soybean food the isoflavones analyses reported 0.1-3.0 mg/g content. Soybean germ products derived from hypocotyledon present one of the most concentrated sources in isoflavones (> 20 mg/g). After ingestion, soybean flavones are hydrolysed by microflora intestinal glycosidases releasing the aglycones daidzein and genistein, and these may be absorbed or metabolised.[26]

Purposes, uses and benefits of soybeans

There are many researches on the benefits of legumes consumption: chickpeas, beans, lentils and soybean, among others.[27] Soybean foods represent an excellent source of high quality protein, are low in saturated fat, and are cholesterol free.[8] But, moreover, soybean contains a great amount of dietary fibre; it is the second largest component in soybeans, and it has shown to reduce risk of colon cancer and other diseases.[11]

Soybean intake and diabetes

Soybean therapy in diabetic individuals depends on the type of diabetes and other factors such as lifestyle and metabolic needs of the patients. Soybean protein has a role in diabetes because of its content in

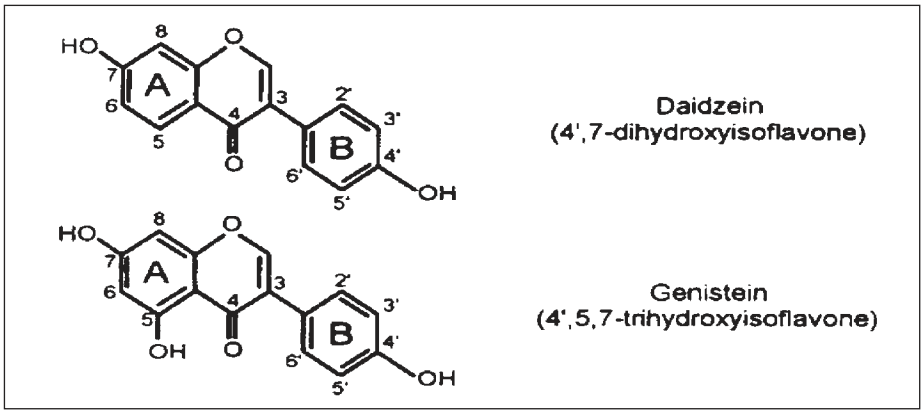


Fig. 4.—Structures of the primary isoflavones in soybean.

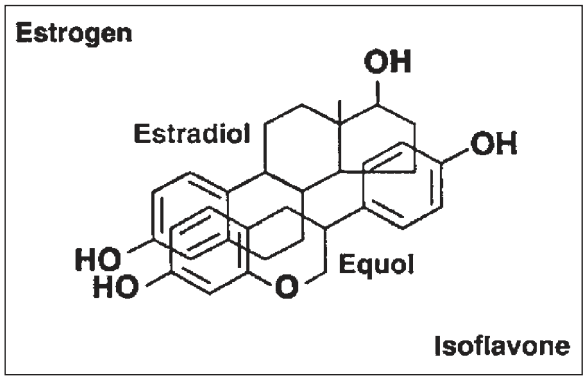


Fig. 5.—Comparison of equol structure (isoflavone metabolite) and estradiol structure (Setchell and Cassidy, 1999).

glycine and arginine, which tend to reduce blood insulin levels. Soybean fibre may be useful because of its insulin-moderated effect.

Soybean diet may be a good option in type 2 diabetes individuals due to its effect on hypertension, hypercholesterolemia, atherosclerosis and obesity, which are very common diseases in diabetic patients.[28]

In addition, substituting animal protein for soybean or other vegetable protein may also decrease renal hyperfiltration, proteinuria, and renal acid load and therefore reduces the risk of renal disease in type 2 diabetes.[29]

It is generally accepted that a high fibre diet, particularly soluble fibre, is useful to control plasma glucose concentration in diabetics. In short- and long-term experiments it has been reported an improvement in blood glucose attributed to fibre intake from soybeans.[8,30]

The mechanisms to improve glycemic control during dietary fibre intake seem to be due to the effects of slowing carbohydrate absorption, so that dietary fibre reduces or delays the absorption of carbohydrates.[30] It also increases faecal excretion of bile acid and therefore may cause a low absorption of fat.[9,29]

One of the most common complications of diabetes mellitus is the development of diabetic retinopathy. The antiangiogenic effects of isoflavones could be of value in this disorder, although the role of soybean protein isolates containing isoflavones has not been studied in detail.[31] In addition, soybean is associated with health benefits for patients with gallstones. The mechanism of beneficial effect of soybean on gallstones is not well known but it may be related to the blood cholesterol lowering effects of soybean protein containing isoflavones.[28]

Researches performed in diabetic patients with soybean diets show several potential advantages,[32] but at the moment very much work is required to define the exact role of soybean in the control of diabetes mellitus.

Soybean intake, cholesterol and heart disease

Cardiovascular heart disease is one of the major health problems in most developed countries. Most deaths due to cardiovascular disease (CVD) are preventable through a lifestyle based on diet, exercise and no smoking.[27]

Several studies corroborate that the regular intake of legumes significantly decreases CVD.[27] Specific studies on soybean remark that the substitution in the diet of animal protein for soybean protein, reduces the concentration of total and low-density lipoprotein (LDL) cholesterol in plasma and decreases triglycerides; high-density lipoprotein (HDL) cholesterol concentrations are not affected significantly.[3] Soybean protein, as well as reducing cholesterol and triglycerides levels, may produce an increase of Lipoprotein A, which is potentially detrimental in antiatherogenic therapy.[33] Nevertheless, consumption of soybean protein helps to reduce cardiovascular disease risk,[3-5] but the mechanisms responsible for the hypocholesterolemic effect have not been identified.

The lack of understanding of this mechanism remains an obstacle for a better acceptance of soybean protein by clinical community. There are different hypothesis to explain these mechanisms. One of these hypothesis is that amino acid composition or distribution in soybean change the cholesterol metabolism, possibly, due to changes in endocrine status, because there are alterations in insulin:glucagon ratio and thyroid hormone concentrations,[34] as well as an increase in plasma thyroxin concentrations which is related with a reduction in plasma cholesterol.[35] Another hypothesis proposes that non-protein components such as saponins, fibre, phytic acid, minerals and isoflavones associated with soybean protein affect cholesterol metabolism. The metabolic changes observed when soybean is introduced in the diet consist in an increased cholesterol synthesis, an increased bile acid synthesis or a faecal bile acid excretion, increased apolipoprotein B or E receptor activity and a decreased hepatic lipoprotein secretion and cholesterol from the blood.[34]

Early epidemiologic researches on dietary fibre from cereals and legumes indicated an inverse relationship between dietary fibre intake and coronary disease risk. Legumes constitute a source of dietary fibre, relatively rich in soluble fibre, which may play an important role in the prevention of heart disease.[5] The major effects of soybean soluble fibres on serum lipoproteins appear to be related with bile acid binding and with a decrease in the reabsorption of bile acid.[27] Therefore, there is an increase in the cholesterol used to synthesize bile acids.[36] But also, the fermentation of soluble fibres in the colon produces short-chain fatty acids that contribute to reduce hepatic cholesterol synthesis.[37] It has been shown that propionic acid, one of the short-chain fatty acids, decreases the hepatic cholesterol.[38] Moreover, the diminution in the synthesis of cholesterol in the liver is due to a reduction in serum insulin concentrations because insulin is responsible of activating an enzyme that participates in cholesterol synthesis and, on the other hand, it

might be due to an alteration of the bile acid profile in the liver.[36]

There is also a hypothesis that isoflavones ingested within a soybean containing diet may inhibit atherosclerotic development, because they have antioxidant properties against LDL oxidation, which generates a cascade of events producing atherosclerotic plaques. In addition, isoflavones possess a hypocholesterolemic effect, although this effect is still under investigation. It might be due to the interaction of isoflavones with estrogenic receptors, because of the structural similitude between these compounds and their metabolites and estrogens. Serum cholesterol concentrations may decrease by similar mechanism.[4] Figure 5 compares the structure of the isoflavone metabolite (equol) with estradiol.

Different clinical researches indicate that to achieve a cholesterol-lowering effect,[32] it is important to consume soybean protein with its natural isoflavones fraction.[39] The hydrolysis of fibres to be used as supplements may also alter their physiological effects. Furthermore, although fibre-rich food is related with protection from CVD and has hypocholesterolemic effects, the separation of its natural compounds such as protein or isoflavones may reduce the cardiovascular and cholesterol effects.[30,37]

Soybean intake and cancer

In the last years, many groups of researchers have suggested that the consumption of soybean is associated with the relatively short levels of different cancers in countries that include soybean in their diets.[8,15,32,40] Soybean foods and isoflavones have received special attention because of their effects in preventing and treating cancer, but it is clear that the data are not enough to conclude the role that soybean consumption plays in cancer.

Researchers have looked at dietary differences between Japan and the Western nations to try to explain variations in death rates from cancer.[41] Within Japanese diet, a number of components of soybean have been investigated for potential anticancer activity. Several researches have demonstrated that soybeans contain high levels of compounds with anticancer activity, such as phytates, protease inhibitors, phytosterols, saponins, phenolic acids, and isoflavones. But most of the data suggest that isoflavones are the responsible ones for the hypothesized anticancer effects of soybean.[8,15,25]

Soybean is unique among legumes because of its isoflavone concentrated source. Isoflavones and their metabolites have several hormonal and non-hormonal activities. The initial interest in isoflavones was because of their estrogenic activity[8] and based on this activity, the possibility to use phytoestrogens containing food in the prevention and treatment of hormone dependent cancers.[42] Now, the prevailing hypothesis is that isoflavones may act like antiestrogen when they are in a high estrogen concentration and like estrogen when they are in a low estrogen environment.[8,15]

One of the two primary isoflavones is genistein that can contribute to the anticancer effects for its antioxidant properties. The anticancer effects are more likely due to the fact that genistein is a specific inhibitor of protein tyrosine kinase, MAP kinase, ribosomal S6 kinase, topoisomerase II, which form part of growth factor-stimulated signal transduction cascades in normal and transformed cancer cells. It has also been proved, *in vitro,* that genistein increases concentrations of TGF-β, which may inhibit the growth of cancer cells. Moreover, genistein has an important role as a potent inhibitor of angiogenesis *in vitro.*[8]

Breast Cancer

The growth of both estrogen-dependent and estrogen independent breast cancer cells *in vitro* has been inhibited by genistein, but it is not clear if the concentrations reached *in vitro* could be reached *in vivo.* The only statement which can be done is that soybean intake may help to prevent the initiation of cancer cells.[8,15] However, although the hypothesis estrogenic-antiestrogenic effects of isoflavones exits, there is evidence of isoflavones increasing estrogenic activity in risk breast cancer women and in women suffering already breast cancer.[40,42] Otherwise, there is no evidence in the literature suggesting that phytoestrogens, in such amounts in human food, stimulate the already existing cancer or initiate cancer. Japanese people with high phytoestrogens plasma levels and having low breast, prostate and colon cancer risk suggest that soybean consumption is not associated with any risk.[43]

Prostate cancer

Estrogens may inhibit prostate cancer growth but also it has been seen that they can be associated with both benign prostatic hyperplasia and prostate cancer. The possible beneficial way of estrogens may not be associated with the estrogen receptor. It is known that estrogens cause programmed cell death of prostate cancer cells and inhibit enzymes associated with different process in the development of cancer.

Soybean foods may be a factor contributing to the diminution of prostate cancer mortality.[43] Genistein has been shown to reduce DNA synthesis in human prostate cells *in vitro* and inhibit testosterone effect in prostate cancer development in rats.[42,44] However, a daily intake of soybean enough to decrease LDL-cholesterol, does not reduce serum prostate specific antigen (PSA) as it has been proposed by others studies.[43]

Colon cancer

There is some epidemiological evidence for protective effects of soybean products on colon cancer but also a number of studies have shown no effect. *In vitro* studies, soybean products have shown an antiproliferative effect on a wide range of cell types including cells of the gastrointestinal tract.[45]

An important role in colon cancer is attributed to dietary fibre, and it also reduces the risk of other chronic diseases in digestive system.[5,30] Dietary fibre can increase the volume of faecal material and reduce the colonic transit time; therefore it prevents a low faecal material and infrequent bowel movements that can produce a prolonged exposition of colonic cells to faecal mutagens. Moreover, fibre may dilute bile acids and provide a dispersed solid phase in which bile salts can be absorbed reducing their concentration in faecal water, because it has been presumed that bile acid salts may cause chronic irritation in the colon and stimulate colonic mucosal proliferation and therefore act as tumour promoters.[30,41]

The fermentation of fibre in colon produces an increase of short-chain fatty acids that present a potential protective effect against colon cancer and bowel infections through inhibition of putrefactive and pathogenic bacteria, respectively.[46,47] Among the short- chain fatty acids, butyrate may act as a regulator of the gene expression that is implicated in colon cells proliferation and differentiation, so it has been proposed that butyrate can be a protection against colon cancer.[48]

Dietary flavonoids have shown antiproliferative role for human colon cancer cells. The antiproliferative property of flavonoids could be linked to their ability to inhibit cellular accumulation of ascorbic acid, which is used during cell division.[49] However, there are results showing that isoflavones do not protect against the development of colon cancer in rats treated with a carcinogen and fed with a high fat diet.[45] Published data about soybean isoflavones and colon cancer are conflicting and scientific evidence in support of the protective effect on colon cancer is limited.[43]

Soybean intake, menopause and osteoporosis

People of western countries compared with many asian people present an increased risk of osteoporosis and have a higher occurrence of many menopausal symptoms. One of the differences between western and asian people is that asian diet is rich in soybean foods compared to western diet.[26]

Researchers found that the daily addition of isolated soybean protein with naturally occurring isoflavones to the diet of postmenopausal women reduced the frequency of hot flashes.[26,50] It would be reasonable to think that in postmenopausal women, isoflavones bind to free estrogenic receptor providing a weak estrogenic effect. This could be useful as a dietary alternative or supplement to postmenopausal hormone replacement therapy.[26,51]

The improvement in cognitive function was observed in postmenopausal women after consumption of soybean extract with isoflavones, but there was not effect on menopausal symptoms. There are two types of estrogenic receptors (ER-α and ER-β) and both are in brain. Isoflavones show preference in binding to ER-β receptor, which is prevalent in brain regions dedicated to cognition. So, it is likely ER-β receptors play a role in cognitive function.[51]

There is a significant positive correlation between calcium excretion and animal protein intake, but this correlation is not present with vegetable protein intake.[52]

Studies have been conducted to investigate the potential effects of soybean products on bone density and osteoporosis risk. Asian people consuming a diet low in animal protein and with a low calcium intake have much lower fracture rates than people in western countries.[8] Consumption of soybean or its isoflavones may be needed to produce moderated increments in bone mass. These findings suggest that isoflavones and soybean protein are responsible for this effects.[52,53]

It has been found that genistein has a direct inhibitory effect on bone resorption[8,54], and daidzein shows an increase of bone mass in postmenopausal women.[8] The mechanisms of isoflavones on bone require to be investigated.

Conclusion

Some nutritional advantages could be obtained by replacing many animal based foods for soybean foods. Soybean represents an excellent source of high quality protein with a low content in saturated fat and a great amount of dietary fibre. Therefore, the possible use of soybean in functional food design is very interesting, since the consumption of soybean protein and dietary fibre seems to reduce the risk of cardiovascular diseases and to improve glycemic control. Furthermore, soybean isoflavones are associated with a potential role in the prevention and treatment of different diseases. Therefore, soybean could play an important role for the promotion of health.

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