



## The nutritional, phytochemical properties, processing of Soybeans, and developed soy foods

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### Abstract

Soybean (*Glycine max*) is a leguminous crop with a lot of nutritional benefits. Besides being a very rich source of protein, soybeans also contain vitamins, minerals, and phytochemicals such as isoflavones, which may be absent in some roots and tubers. Soybean processing is essential as it improves their nutritional value, safety, and functionality, making them a more valuable and versatile crop. There exist different types of developed soy foods in the market that come with varied flavours and textures, and a low-fat, nutritionally balanced diet. The nutritional and phytochemical quality of soybeans and associated health benefits were reviewed. This article also covers the significance of processing soybeans while addressing the adverse effects of over-processing or overheating. It concluded by addressing soy foods and recently developed soy foods in the market, with the intention to inspire further research on innovative soy foods, aimed at reducing food waste and enhancing the sustainability of the soybean processing industry.

**Keywords:** Soy antioxidants, processing methods, processing effects, recent soy foods

### Introduction

The soya bean (*Glycine max*) in Europe, also called soybean in North America, is one of the most widely grown leguminous crops in the world that is grown in the tropical, subtropical, and temperate climates (Lisanti and Arwin, 2019) [17]. It is a good source of high-quality protein and oil, and has wide applications across the food, feed, and industrial sectors. In recent years, the global demand for soybeans has surged due to their versatility in various consumer products, including tofu, soy milk, and soy-based meats. The UN Food and Agriculture Organization (FAO) classified soybean as an oilseed rather than a pulse due to its high protein quality and abundant lipids, which qualify it as a very nutritious plant (Chikezie, 2016) [16]. Besides protein, soybeans also contain minerals, vitamins, and even phytochemicals such as isoflavones, which may be absent in some roots and tubers (Uwem *et al.*, 2017) [32]. Other components of soybean include saponin, protease inhibitors, phytic acid, and fiber, and therefore soybean could be regarded as a functional food (Malencic *et al.*, 2012) [19]. Soybean contains about proteins (40%), lipids (20%), minerals (5%), and B vitamins, and it is hypothesized that the consumption of soybean products reduces cancer, the risk of coronary heart disease, oxidative stress, bad cholesterol, osteoporosis, chronic renal disease, and others (Agume *et al.*, 2107). The lower rates of chronic diseases such as cardiovascular diseases and certain types of cancer recorded in Asian countries have been associated with the intake of large amounts of soy foods (Wu and Kang, 2011) [34]. However, there are some non-toxic biologically active substances present in soybeans - the trypsin inhibitors, hemagglutinin, goitrogens, urease, tannin, and phytic acid. These substances, if not removed through processing, may inhibit the availability of desired substances or reduce the nutritional value of soybeans (Samuel *et al.*, 2012) [29]. The health benefits associated with the consumption of soybeans and soy products led to an increase in demand for the

legume. The high demand in turn stimulated a significant increase in soybean production from 200 million metric tons in 2005 to 324 million metric tons in 2016 (Agume *et al.*, 2017).

The demand for soybeans around the world has grown a lot in the last few years because they can be used to make a lot of things that people buy, like soy milk, soy-based meats, and tofu. But when soybeans are processed the old-fashioned way, they often make a lot of byproducts that can waste resources if they aren't used. The various processing methods of soybeans and opportunities to increase the value of soy-based goods and byproducts were analyzed in this paper, aimed at fostering sustainability within the soybean sector (Kanimozi, 2018; Karim *et al.*, 2025) [11, 12].

### Soybean Nutritional Benefits

The seeds of the soya plant are an excellent source of macronutrients (protein, carbohydrate, and lipid). Its composition may vary depending on the varieties and the growing conditions. Burssens *et al.* (2011) [4] described the proximate composition and some mineral contents of the whole seed of soybean in comparison with some soy products - soy milk, tofu, and soy sprouts, as shown in Table 1.0:

#### 1. Carbohydrates

The carbohydrate of soybeans is about 30 to 35%, and is composed of little starch and hexose, are majorly polysaccharides with some oligosaccharides. The soluble carbohydrates in soybeans are about 10-13%, of which sugars (fructose, sucrose, saccharose, raffinose, and stachyose) represent 10-12% and starch 1% (Burssens *et al.*, 2011) [4]. Galacto-oligosaccharides, which include raffinose, stachyose, and verbascose, cannot be broken down by human digestive enzymes but by the bacteria present in the small intestine with gas production in the intestine (flatulence) (Burssens *et al.*, 2011) [4]. Flatulence is a

problem with soy products due to the oligosaccharides mentioned. Fermentation, leaching, and sprouting soybeans may reduce cases of flatulence when soy products are consumed (Lokuruka, 2010) [18]. Soybeans comprise fibers which are a mixture of cellulosic and noncellulosic structural components (cellulose, hemicellulose, and pectin substances). Dehulled SB flour contains 6.2% neutral fiber, 5.7% acid detergent fiber, 4.6% crude cellulose, 0.5% crude hemicellulose, and 1.3% lignin, while soy concentrates contain slightly higher fiber; soy proteins have none (Lokuruka, 2010) [18]. Dietary fibre is important in human

nutrition because it increases the weight and size of your stool and softens it. Increased stool bulk is easier to pass, decreases the chances of constipation, and increases transit time. This may reduce diverticular disease, haemorrhoids, and other lower gastrointestinal tract diseases. The effect of soy on chronic diseases may depend on specific bioactive substances and primary isoflavones, and the protective action involves an anti-inflammatory, antineoplastic, and antiplatelet mechanisms, and, at least in part, antioxidant mechanisms (Rizzo, 2020) [27].

**Table 1:** Nutritional composition of soybean, soymilk, tofu and soy sprouts

Per 100 g	Soybean	Soy milk	Tofu	Soy sprouts
Proteins (g)	38.00	3.70	12.00	5.50
Fat (total) (g)	18.00	2.20	7.00	1.00
saturated fatty acids (g)	2.50	0.40	0.00	0.00
mono-unsaturated fatty acids (g)	4.00	0.50	0.00	0.00
poly-unsaturated fatty acids (g)	10.70	1.30	0.00	0.00
-linoleic acid ( $\Omega$ -6) (g)	9.80	1.20	0.00	0.00
-alpha-linolenic acid ( $\Omega$ -3) (g)	0.90	0.20	0.00	0.00
Carbohydrates (g)	6.30	2.80	1.00	4.70
Fibers (g)	22.00	0.60	0.00	2.38
Calcium (mg)	201.00	120.00	87.00	32.00
Magnesium (mg)	220.00	0.00	94.00	235.00
Potassium (mg)	0.00	0.00	94.00	235.00
Vit B2 (mg)	0.00	0.20		

Source: Burssens *et al.* (2011) [4]

## 2. Soybean Protein

Soy protein offers a “complete” protein profile unlike some other legumes, and its products can be used as good substitutes for animal products. Apart from methionine, soybeans contain all the essential amino acids. Essential amino acids must be supplied externally from our diet because they cannot be synthesized by the human body. Soybean protein contains an amino acid composition that complements that of cereals. In other words, soybeans contain sufficient lysine to complement or take care of lysine deficiency in cereals. For example, soybean, when combined or consumed with maize or rice, will overcome or complement the deficiency of lysine and methionine in rice. Another particularly valuable health importance of soybean proteins is that they contain all amino acids essential, comparable to animal sources in terms of protein quality, but have less saturated fat and no cholesterol (Xiao, 2008) [35]. In other words, soy products can replace animal-based foods, which also contain complete proteins but tend to have more saturated fat. Soybean protein contains all the basic amino acids reported to have about 92% edibility, which matches that of creature protein like egg white and casein (Saha and Mandal, 2019). Soybean flour, in several studies, has been incorporated in other flours made from cereals and tubers to get food products with significant improvement in their protein content (Olapade and Akinyanju, 2014; Biji *et al.*, 2013; Samuel *et al.*, 2012; Ndife *et al.*, 2011) [1, 20, 29].

In combination with cereals that are richer in those essential amino acids that are deficient in legumes, such as methionine, cysteine, and tryptophan, legumes are beneficial for human health and for the world’s ecology. The optimum protein quality is approximated when 60-70% cereals are mixed with 30-40% cooked legumes. This would produce a combined quality of protein comparable with meat (Burssens *et al.*, 2011) [4].

## 3. Lipids

Soybean contains about 20% total lipids (crude oil), which of the following (Burssens *et al.*, 2011) [4]:

- Triglycerides (constitute about 96% of the total lipids of soybean);
- Phospholipids or lecithins (constitute about 2%) are used as emulsifiers in the medical and food industries.
- Unsaponifiable lipids (about 1.6 %), mainly tocopherols (Vit E) and sterols
- Free Fatty acids (only 0.5 %)

Soybean oil provides calories, the essential fatty acids, and fat-soluble vitamins like vitamins A and E, but contributes very low amounts of Vitamins D and K (Lokuruka, 2010) [18]. The high iodine value (134) of soybean oil is similar to that found in sunflower oil. Peanut butter, maize, and palm oils have higher iodine values of 101, 127, and 51, respectively (Lokuruka, 2010) [18]. Iodine values indicate the level of unsaturation in oil. The higher the iodine value, the lower the level of unsaturation. The fatty acids in soybeans are considered ‘heart-healthy balanced’ due to their high mono and polyunsaturated fatty acids (80 % of total fatty acids primarily in the form of linoleic acid) contents and low contents of saturated fatty acids (20 %) (Lokuruka, 2010) [18]. Due to considerable unsaturation, linoleic acid in our diet reduces serum cholesterol. The essential fatty acid, alpha-linolenic acid (ALA), an omega-3 fatty acid in our body may protect against coronary heart disease. And soybean is rated as one of the few good plant sources of these essential fatty acids (Burssens *et al.*, 2011) [4].

## 4. Mineral in Soybean

The ash content (mineral) in soybeans is approximately 5% of dry mass, and its major constituents are calcium, potassium, and magnesium (Burssens *et al.*, 2011) [4]. Other minerals, such as Iron, copper, and zinc, present in soybeans are trace elements (Burssens *et al.*, 2011) [4].

Soy beans' potassium content is the highest, followed by phosphorus, magnesium, sulphur, calcium, chloride, and sodium in that order (Lokuruka, 2010) <sup>[18]</sup>. Other minor minerals found in soybeans include silicon, manganese, molybdenum, fluoride, chromium, selenium, cobalt, cadmium, lead, arsenic, mercury, and iodine. Calcium is essential for building strong bones and teeth. Soy flour has high calcium content (about 300.36 mg/100g) and could be used to complement foods deficient in calcium. Calcium is also involved in muscle contraction, blood clotting, nerve impulses, and others (Piste *et al.*, 2013) <sup>[24]</sup>. Deficiency in calcium or vitamin D may cause a medical condition known as Osteoporosis. Osteoporosis is a bone disease in which the bones become weak and brittle from loss of tissue, and can lead to hip fractures, especially in older women. Epidemiological studies have observed relatively fewer fractures and greater bone density among the Asian population who take large quantities of soy products, such as tempeh, tofu, and miso, than the Western population (Bolla, 2015) <sup>[2]</sup>.

The two minerals, phosphorus and calcium, work in synergy to form calcium phosphates, which give bones their rigid structure (Ogbemudia *et al.*, 2017) <sup>[22]</sup>. Magnesium is essential in synthesizing proteins and releasing energy; it also helps in holding calcium in the enamel of the teeth (Ogbemudia *et al.*, 2017) <sup>[22]</sup>. Iron is used in the

management of iron deficiency anemia, since iron is an essential element for blood production, and is found in red blood cells that transfer oxygen in the blood from the lungs to the tissues. There are reports that mineral bioavailability from the consumption of plant foods is less when compared with that of animal foods. For instance, calcium, zinc, and phytate in soy foods chemically combine to form a highly insoluble complex that greatly lowers zinc bioavailability than phytate alone. It has also been reported that haeme iron from animal foods is more readily absorbed than the non-haeme iron found in soybeans (Lokuruka, 2010) <sup>[18]</sup>.

### Some Phytochemicals and Antioxidants in Soybean

Phytochemicals are a large group of plant-derived compounds hypothesized to be responsible for much of the disease protection provided by vegetables, fruits, peas, cereals, and plant-based beverages such as tea and wine (Arts and Hollman, 2005). Phytochemicals are classified based on their structures, as shown in Figure 1.0.

#### 1. Saponins and Sapogenols in Soy

Saponins are naturally occurring surface-active glycosides with a distinctive foaming characteristic (Desai *et al.*, 2009) <sup>[6]</sup>. They are found in most vegetables, beans, and herbs, and the best-known sources of saponins are peas and soybeans (Wu and Kang, 2011) <sup>[34]</sup>.

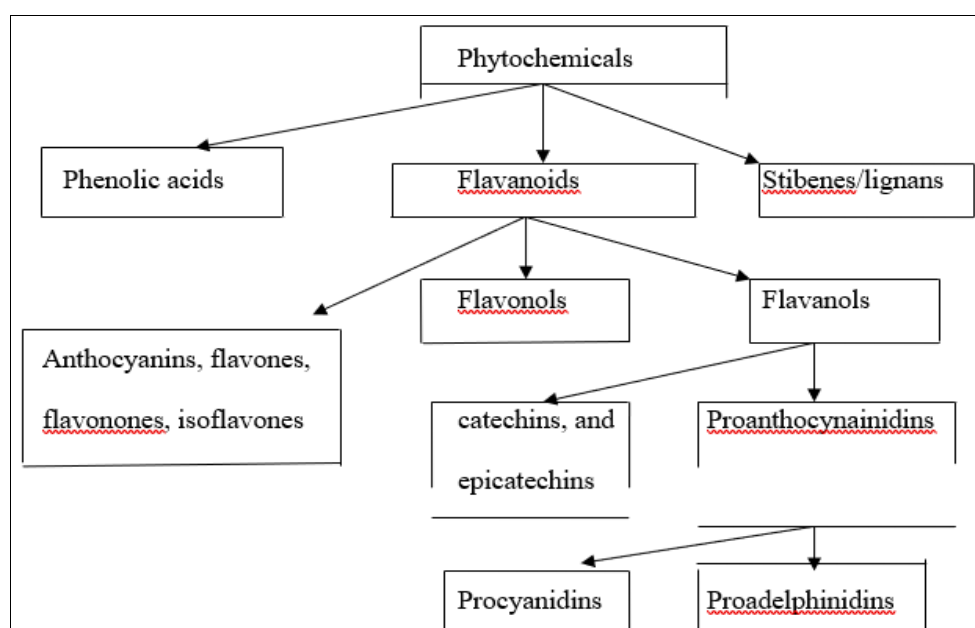


Fig 1: Classification of Phytochemicals

Soya saponins and soya sapogenols are known to be anticancer, anti-virus, hepatoprotective, protect against cardiovascular diseases, and have antioxidant properties (Wu and Kang, 2011) <sup>[34]</sup>. The saponins from different sources are known to reduce blood cholesterol levels in human subjects and in a variety of animals. When foods rich in saponins, such as soybean, chickpea, and lucerne, are consumed, they form large mixed micelles by the interaction of saponins with bile acids, which accounts for their increased excretion. This increased metabolism of cholesterol in the liver causes a reduction of serum cholesterol (Desai *et al.*, 2009) <sup>[6]</sup>. Due to this increasing evidence of saponins' health benefits, such as cholesterol-lowering and anticancer properties, there has been in recent

years renewed concentration on food and non-food sources of saponins (Guclu-Ustundag and Mazza, 2007) <sup>[8]</sup>.

#### a. Phenols

Besides oil and proteins, soybeans contain phenols, sometimes called phenolics. Foods that have high phenol content include tomatoes, apples, peanuts, bananas, oranges, cocoa, red grapes, colored fruits, and milk (Wikipedia, 2020). Primary metabolites of phenols are essential for growth, reproduction, and development, while secondary metabolites such as phenolics are associated with plant defence against pests and survival mechanisms under abiotic and biotic stress (Prvulović *et al.*, 2016). Phenolic compounds are of considerable importance in human diets

because they neutralize free radicals by donating a hydrogen atom or by a single electron transfer mechanism (Chikezie, 2016) <sup>[5]</sup>, and thereby reduce the risk of degenerative diseases such as cancer, atherosclerosis, and coronary heart disease. Soybean phenols have been shown to possess some unique structures that make the phenolics inherently excellent hydrogen or electron donors, which enable them to readily stabilize or neutralize some harmful reactive oxygen species (Prvulović *et al.*, 2016).

#### b. Flavonoids/Isoflavones

Flavonoids are generally found in all plants, while isoflavones (3-phenyl-4H-1-benzopyran-4-one) are a subclass of more ubiquitous flavonoids. For over one hundred years (100 years), isoflavones have been known to be present in plants, and soy, including soy foods, is known as the richest dietary source of isoflavones (Wu and Kang, 2011) <sup>[34]</sup>. Flavonoids are the most common group of polyphenolic compounds in the human diet. Health-promoting effects of soybean have been attributed to its antioxidative effect, as well as to the estrogen-like activity of isoflavones, which has been reported to reduce the risk of breast cancer and osteoporosis (Josipović *et al.*, 2016) <sup>[10]</sup>. Also, flavonoids are known as one of the most potent plant antioxidants and the most widely distributed phenolic compounds in plant foods, as well as the most researched ones (Xiao, 2008) <sup>[35]</sup>.

#### c. Tannins

Tannins form complexes with proteins and thus precipitate proteins in the gut, thereby reducing their digestibility. They can cause an astringent reaction in the mouth and make food unpalatable. Tannins can also interfere with dietary iron absorption (Samuel *et al.*, 2012) <sup>[29]</sup>.

#### Soybean Processing

Several processing methods are employed in soybean processing, each aimed at producing protein-rich products, oil, and valuable food ingredients from soybeans. The major processing methods include mechanical extraction, solvent extraction, fermentation, and hydrothermal treatment, which are used for the production of the following: soy protein concentrates, oil, soy isolates, and other derivatives like soy lecithin, which have broad applications in food products and industrial uses. Soybean processing generally begins with cleaning/sorting, soaking/parboiling, and grinding the beans, followed by oil extraction. The remaining cake is processed to obtain soy protein, which is used in many food products such as soy burgers, milk, and protein isolates.

However, during these processes, several byproducts like okara, soy whey, and soy hulls are produced. A significant number of these byproducts are underutilized, and this results in considerable environmental and economic waste (Lyu *et al.*, 2023) <sup>[16]</sup>. Okara, the fibrous material left over after extracting soy milk, is one of the most promising byproducts. It is a nutrient-rich byproduct that can be used in animal feed, functional foods, or even bioplastics (Krishnan & Darly-Kindelspire, 2013) <sup>[13]</sup>. The nutrient composition of okara includes fiber, protein, and essential minerals, making it suitable for use in dietary supplements, meat substitutes, and even bioactive compounds like oligopeptides (Karim *et al.*, 2025).

#### Soybean Processing Methods and Their Importance

- 1 Cleaning and Dehusking:** these remove impurities, seed coats, and stones, while dehulling improves protein digestibility and soybean oil.
- 2 Heat Treatments:** Roasting, extrusion, toasting, and parboiling are heat treatments given to soybeans. They inactivate anti-nutritional factors such as trypsin inhibitors, lectins, but some heat-sensitive vitamins may be lost in the process (Kumar *et al.*, 2017) <sup>[14]</sup>. Parboiling soybeans improves digestibility, enhances nutrient bioavailability, makes the texture softer for easier processing (Singh *et al.*, 2016), and improves mineral absorption.
- 3 Mechanical and Solvent Extraction:** Oil recovery is enhanced through this process. However, the protein functionality may be affected depending on some factors.
- 4 Fermentation:** Products from soy, such as tempeh, soy sauce, and natto, are fermented to improve flavour, digestibility, and bioactive compounds such as isoflavones and peptides (Rani *et al.*, 2021) <sup>[25]</sup>.
- 5 Enzymic and Chemical Processing (as in textured soy protein, protein isolates, and concentrates):** This enhances functionality for food applications, but some micronutrients might be lost during this process.
- 6 Refining and Fractionation:** these methods produce oil fractions and protein with sustainable qualities, improved shelf life, and better organoleptic quality (Kumar *et al.*, 2017) <sup>[14]</sup>.

However, processing of soybeans has some negative effects, which include the following:

- 1 Protein denaturation.** Excessive heat or over-processing can cause protein denaturation, which affects functionality.
- 2 Loss of Nutrients.** Over-processing can lead to loss of nutrients, especially vitamins and minerals.
- 3 Texture degradation.** Excessive processing can lead to undesirable changes in texture (Singh *et al.*, 2014).
- 4 Production of undesirable compounds.** Certain processing techniques can lead to the generation of unwanted compounds, such as advanced glycation end-products (AGEs) (Rinaldi *et al.*, 2018) <sup>[26]</sup>.

#### Soy Foods

Some soybean food products, such as soy milk, tofu, TVI, and fermented food products such as miso, tempeh and soy sauce, have been described as the most considerable dietary source of isoflavones in human nutrition (Rizzo and Baroni, 2018) <sup>[28]</sup>, and have gained significant popularity due to their favorable nutritional profiles characterized by low cholesterol levels and high protein content (Karim *et al.*, 2025) <sup>[12]</sup>.

#### Soymilk

Soymilk is produced from water extraction of hulled and crushed soybeans. The beany flavour within soymilk is removed by the heating process (boiling) after filtration of raw milk. Soymilk drink provides eight essential amino

acids for humans (Chen *et al.*, 2012) <sup>[3]</sup>, and it can be consumed by all sections of people suffering from lactose intolerance (infants/youths/old/pregnant, etc) (Ghandhi, 2009). Raw soymilk serves as the base of different types of soy products, including tofu, soy yogurt, and cheeses (Chen *et al.*, 2012) <sup>[3]</sup>. The soy milk, when packed in tetra packs, can last up to six months, but has a shelf life of a few weeks under refrigerated conditions (Ghandhi, 2009).

### Tofu

Tofu, also called soybean curd, is manufactured by adding a coagulant (salt or acid) to the extracted soymilk from ground, soaked soybeans and pressed to form tofu. The addition of calcium or magnesium salts to soy milk enables the soy protein to coagulate to form curd. When the tofu is made with calcium, Calcium becomes an essential component of tofu when it is made with calcium (Ghandhi, 2009). Fresh tofu can be divided into three main types: Soft/silken, firm, and dried tofu, depending on the amount of water that is pressed out from the tofu curds. The softer one is preferably used for desserts or other foods, while the dry or extra firm tofu is often used for marinating and cutting into cubes for a stir-fry (Jooyandeh, 2011) <sup>[9]</sup>, and eaten as snacks or meat analogues. With novel pasteurization and packing techniques, tofu can be stored up to one year (Chen *et al.*, 2012) <sup>[3]</sup>.

### Soy sauce

Soy sauce is fermented with different bacteria, yeast, or treated with isolated enzymes. Pressing and filtration after fermentation are needed to extract the aqueous phase. The fermented paste was pressed to yield liquid. This savory seasoning sauce is now widely used in both Oriental and American cuisine.

### Miso

Miso is traditional fermented soy beans with *Aspergillus oryzae* or *Aspergillus soyae*. Nowadays, more soybean products have been commercialized, ranging from dietary supplements to animal husbandry, because of their high nutritional content and many bioactive ingredients.

### Tempeh

Tempeh is a traditional fermented dehulled soybean cake from black or yellow soybeans fermented with *Rhizopus oligosporus*. Deep-frying of tempeh led to a loss of isoflavone content by almost 45%, as temperature is critical to isoflavone retention (Rizzo and Baroni, 2018) <sup>[28]</sup>.

### Textured Vegetable Protein (TVP)

TVP is made by extrusion and cooking wholly from either defatted soy meal flakes or soy protein concentrates, in moisture and temperature-controlled conditions. It is widely used as an ingredient in ground meat for patties, sausages, and meatloaf, and in vegetarian foods and stews (Jooyandeh, 2011) <sup>[9]</sup>. Textured proteins are produced in different sizes, shapes, and colors, and can be flavored to resemble meat or poultry products, which they replace. TVP is a good source of protein in the form of soy meat analogues and is comparable in terms of protein digestibility with beef. TVP defatted soy flour had protein digestibility of 66.1%, 63.4% for TVP protein concentrate, while beef had protein digestibility of 73.2% (Rizzo and Baroni, 2018) <sup>[28]</sup>.

### Recent Soy Developed Foods

In our supermarkets, presently in advanced countries, are displaying tofu meat, tofu with mango, with berries, tofu burgers, tofu dogs, tofu sliced meat, tofu cutlets, soy dream mocha fudge, tofu ice cream, etc (Lokuruka, 2010) <sup>[18]</sup>. These products attracted and were cherished by buyers because they are relatively cheap as well as tasty, having been blended with additives that improve flavour.

### Conclusion

Soybeans have a lot of nutritional and health benefits. In addition to that, many foods have been developed from soy products, which are generally relatively cheap and loaded with nutrients when compared with other nutrient-packed foods. Nigerian Food scientists should begin to develop soy products with our local fruits, and include them in our confectioneries.

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