Chapter 1
Soybean (*Glycine max*)

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Abstract Soybean (*Glycine max*), also called as soja bean or soya bean, holds tremendous economic importance owing to its high amount of oil content (18%), high-quality proteins (~40%), contribution toward soil fertility, high productivity, and profitability; and, thus, is rightly referred to as the miracle crop. Soybeans are also a significant source of polysaccharides, soluble fibers, phytosterols, lecithins, saponins, and phytochemicals mainly isoflavones which either individually or collaboratively help in promoting health by reducing the incidence of debilitating diseases like hyperglycemia, hypertension, dyslipidemia, obesity, inflammation, cancer, etc. Century-old literature shows that soybean seeds have been primarily used in Asia to prepare a variety of fresh, fermented, and dried foods, viz., soy milk, tofu, soy paste, soy sauce, miso, natto, etc. which have now become popular all over the world. Furthermore, soybean and its products find various non-food applications such as in the production of papers, plastics, pharmaceuticals, inks, paints, varnishes, pesticides, cosmetics, and, more recently, biodiesel.

Keywords Soybean (*Glycine max*) · Isoflavones · Soy products · Antiadipogenic · Anticancer · Hypoglycemic · Soy protein isolates

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B. Tanwar, A. Goyal (eds.), *Oilseeds: Health Attributes and Food Applications*,
https://doi.org/10.1007/978-981-15-4194-0_1

1.1 Origin and History

The cultivation of soybeans (*Glycine max*) was started some 4000–5000 years ago, with its origin being traced back to China (Qiu and Chang 2010), Japan, and Korea. Kwon et al. (2005) reported occurrence of carbonized soybeans at some historic sites in Korean Peninsula, thus providing a strong evidence for its cultivation from the Bronze Age. Engelbert Kaempfer, a German botanist, has been credited with the introduction of soybean to Europe in the eighteenth century, but poor climatic and soil conditions limited its production in the continent. Soybean cultivation began in the United States only in the nineteenth century and has been a significant commercial crop since then. Apart from the US Food and Drug Administration (FDA) approving the health claims which linked soybean to reduction in the coronary heart diseases in 1999, the availability of transgenic soybean, the existence of regulatory biosafety frameworks, and the incorporation of new land and innovative agricultural technologies by farmers provided the impetus to the popularization of soybean in the United States and world at large (Qiu and Chang 2010).

1.2 Production

Three countries, viz., the United States, Brazil, and Argentina, dominate global production and account for approximately 80% of the world's soybean supply. United States accounts for 34% and 18% of the world's production of soybean and soya oil, respectively (Table 1.1). Owing to the fact that soybean holds 25% share of the global vegetable oil production, two-thirds of the world's protein concentrate, and an essential ingredient in the fish and poultry feeds, it has now acquired the prominent place as the world's most important seed legume. This fact is evidently seen in the data presented in Fig. 1.1, wherein, the increasing production

Table 1.1 World production of soya grain and oil (2018–2019)

Country	Production (million metric tons)	
	Soybean grain	Soya oil
USA	123.664	10.093
Brazil	117.0	8.195
Argentina	55.00	8.415
China	15.90	15.949
India	11.00	1.620
Paraguay	9.50	0.740
Canada	7.30	0.366
Mexico	0.34	0.946
European Union	2.70	3.154
Others	18.589	6.591
Total	360.993	56.069

Source: USDA (2019)

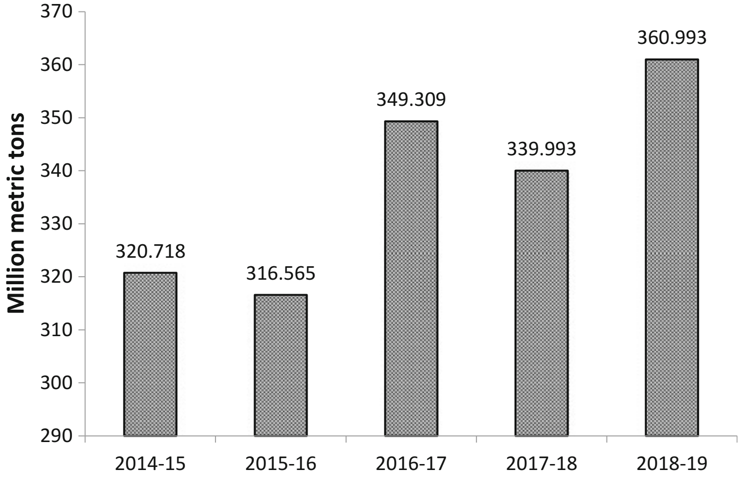

Fig. 1.1 Global production of soybean (USDA 2019)

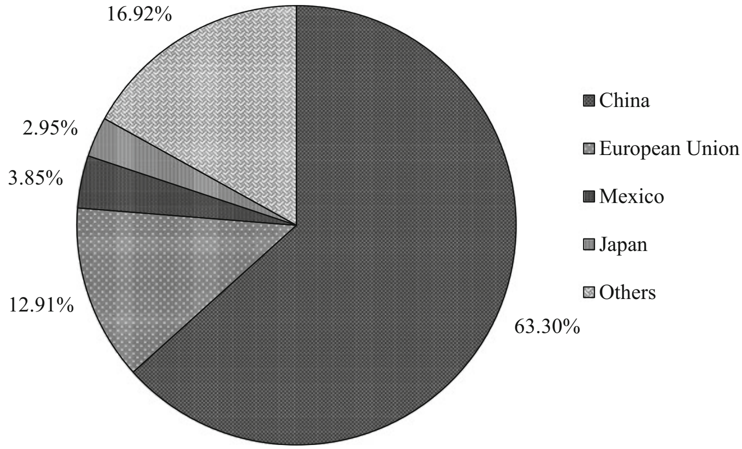

Fig. 1.2 Soybean-importing countries and their share (USDA 2019)

trend of soybean at global level for the last 5 years is illustrated. According to the Product Complexity Index (PCI), soybeans are the 44th most traded product and the 978th most complex product. The data pertaining to the export and import of soybean is depicted in Figs. 1.2 and 1.3, respectively. Globally, every year approximately 85% of the soybeans are processed into soybean meal and oil, of which 95% oil is consumed as edible oil, and 5% is utilized in the industrial production of biodiesel, soaps, and fatty acids. On the other hand, approximately 98% of the soybean meal is utilized in animal feed and the rest in soy proteins and flour (USDA 2019).

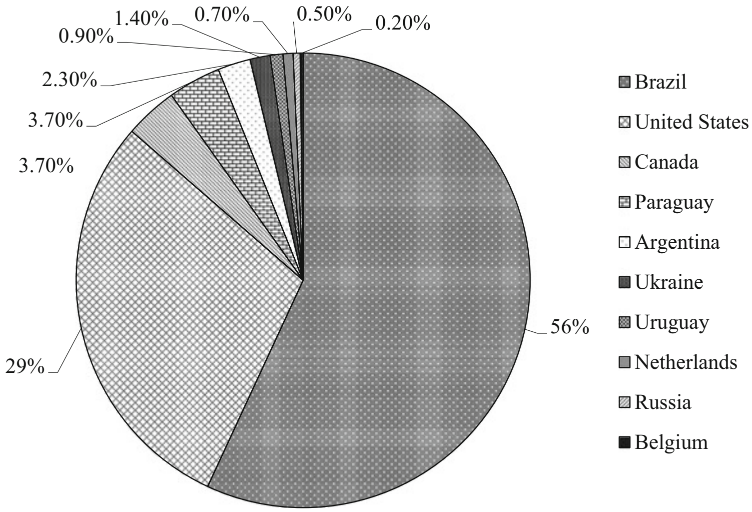

Fig. 1.3 Soybean-exporting countries and their share (USDA 2019)

1.3 Nutritional Composition

Among legume seeds, soybeans contain not only the maximum crude protein but also the best amino acid composition and, hence, are considered the best vegetable protein source for humans as well as animals. However, it is important to note that the composition of whole soybean and its structural parts is highly dependent on geographic location, growing season, environmental stress, and variety of the seed.

1.3.1 Carbohydrates

Carbohydrates are the second largest component (22.11–33.18%) in soybeans (Warle et al. 2015; Alghamdi et al. 2018). Previously, soy carbohydrates held much less economic importance than soy protein and oil due to the thought that it just provides calories. Also, its digestion was better in monogastric animals and, hence, was primarily used in ruminant feeds. However, the picture is changing now due to the recent emphasis on the role of dietary oligosaccharides and dietary fiber in preventing colon cancer and other diseases (Benito-González et al. 2019).

The hull comprises 8% of the seed and contains approximately 86% carbohydrates, whereas hypocotyl axis and cotyledons comprise 2% and 90% of the whole seeds and contain 43% and 29% of carbohydrates, respectively (Liu 1997). Soybeans contain sucrose (2.5–8.2%), raffinose (0.1–0.9%), stachyose (1.4–4.1%), and trace amounts of glucose and arabinose (Hymowitz et al. 1972). Raffinose and stachyose are the limiting factors for its utilization as food due to their poor digestion, flatulence, and abdominal discomfort in humans (Steggerda et al. 1966). Also, it has been observed that these oligosaccharides are poorly metabolized by ruminants and, thus, decrease its nutritive value (Coon et al. 1988). Nevertheless, efforts have been made to reduce these negative effects by fermentation and germination (Neus et al. 2005).

The cell walls of the soybeans contain insoluble carbohydrates, viz., cellulose (20%), hemicellulose (50%), pectin (30%), and some amount of starch (12%) (Warle et al. 2015). Polysaccharides, oligosaccharides, lignin, and associated plant substances are termed dietary fiber and range between 9% and 16% in whole soybeans (Esteves et al. 2010). Insoluble fraction (74–78%) is mainly composed of arabinose, galactose, glucose, xylose, and uronic acids, and soluble fiber (22–26%) comprises of arabinose, galactose, and uronic acids (Redondo-Cuenca et al. 2007). Although they do not contribute nutritionally, they are now considered as an integral part of the diet as they confer many health-protective effects, viz., reducing the risk of coronary heart disease (Liu et al. 1999), stroke (Steffen et al. 2003), hypertension (Whelton et al. 2005), diabetes (Montonen et al. 2003), obesity (Lairon et al. 2005), and certain gastrointestinal disorders (Petruzziello et al. 2006).

1.3.2 Proteins

Protein content of soybean ranges from 33% to 45% (Machado et al. 2008). Soy protein has garnered a lot of attention lately owing to it being at par with animal proteins both in quantitative and qualitative terms and being the only vegetable food containing all eight essential amino acids (Dudek 2013; Hark and Morrison 2000). Methionine and cysteine are the only limiting factors in soybean; nevertheless, the Protein Digestibility Corrected Amino Acid Score (PDCAAS) for whole soybeans is 0.92 which indicates that soy protein is excellent for human nutrition in terms of both the amino acid pattern and protein digestibility. Thus, suggesting that soy food consumption is the best way to increase protein consumption in vegetarian population (Burssens et al. 2011). In terms of protein characterization, just like other legumes, the bulk of soybean proteins are the globulins. The four major fractions are β-conglycinin (principal component), glycinin (principal protein), trypsin inhibitors, and enzymes and hemagglutinins (Burssens et al. 2011). Among these, glycinin and α-, β-, and γ-conglycinin constitute the major legume storage proteins (Wolf 1970).

1.3.3 Lipids

The total fat content of soybean ranges from 16% to 22%. Among all the other legumes, it contains highest amount of fat and contributes nearly 47% to its energy

Table 1.2 Nutritional profile of soybeans (per 100 g dry matter)

Composition	Soybean seeds	Composition	Soybean seeds
Carbohydrate	30.16 g	**Ash**	4.87 g
Total dietary fiber	9.3 g	**Minerals**	
Total sugars	7.33 g	Calcium, Ca	277 mg
Protein	36.49 g	Iron, Fe	15.7 mg
Amino acids		Magnesium, Mg	280 mg
Tryptophan	0.591 g	Phosphorus, P	704 mg
Threonine	1.766 g	Potassium, K	1797 mg
Isoleucine	1.971 g	Sodium, Na	2 mg
Leucine	3.309 g	Zinc, Zn	4.89 mg
Lysine	2.706 g	Copper, Cu	1.658 mg
Methionine	0.547 g	Manganese, Mn	2.517 mg
Cystine	0.655 g	Selenium, Se	17.8 μg
Phenylalanine	2.122 g	**Vitamins**	
Tyrosine	1.539 g	Vitamin C	6 mg
Valine	2.029 g	Thiamin	0.874 mg
Arginine	3.153 g	Riboflavin	0.87 mg
Histidine	1.097 g	Niacin	1.623 mg
Alanine	1.915 g	Pantothenic acid	0.793 mg
Aspartic acid	5.112 g	Vitamin B_6	0.377 mg
Glutamic acid	7.874 g	Folate, total	375 μg
Glycine	1.88 g	Choline, total	115.9 mg
Proline	2.379 g	Betaine	2.1 mg
Serine	2.357 g	Vitamin B_{12}	0 μg
Total lipid	19.94 g	Vitamin A, RAE*	1 μg
Fatty acids (FA)		Retinol	0 μg
Total saturated FA	2.884 g	β-Carotene	13 μg
Myristic acid (C14:0)	0.055 g	Vitamin A, IU	22 IU
Palmitic acid (C16:0)	2.116 g	Vitamin E (α-tocopherol)	0.85 mg
Stearic acid (C18:0)	0.712 g	Vitamin K (phylloquinone)	47 μg
Total monounsaturated FA	4.404 g		
Palmitoleic acid (C16:1)	0.055 g		
Oleic acid (C18:1)	4.348 g		
Total polyunsaturated FA	11.255 g		
Linoleic acid (C18:2)	9.925 g		
Linolenic acid (C18:3)	1.33 g		
Total trans FA	0 g		
Cholesterol	0 mg		
Phytosterols	161 mg		

Source: USDA (2019)
*RAE: Retinol Activity Equivalents

value (Liu 1999; Messina 1999; Burssens et al. 2011). Triglycerides have the highest percentage (96%), followed by phospholipids or lecithin (2%), unsaponifiable lipids (1.6%), and free fatty acids (0.5%). As shown in Table 1.2, it is a good source of mono- and polyunsaturated fatty acids and essential fatty acids and poor source of saturated fatty acids and, thus, has been approved 'Heart-healthy' by the American Food and Drug Administration, the British Joint Health Claims Initiative, and the American Heart Association (Sacks et al. 2006).

1.3.4 Vitamins

The vitamin content of soybeans is presented in Table 1.2. In soybean, vitamin E is available in substantial amount with α-tocopherol (0.4–8 mg/100 g dried weight), γ-tocopherol (4–80 mg/100 g), δ-tocopherol (1–50 mg/100 g), and trace amount of β-tocopherol (Kasim et al. 2010; Li et al. 2010).

1.3.5 Minerals

Ash content in soybean ranges from 4.5% to 6.0% (Monteiro et al. 2003; Burssens et al. 2011). Potassium is found in the highest concentration, followed by phosphorus, magnesium, and calcium; whereas, iron, sodium, zinc, copper, and manganese are present in minor and selenium in trace amounts (Please refer to the mineral composition in Table 1.2).

1.3.6 Antinutrients and Phytonutrients

Soybean is a good source not only of protein, oil, and minerals but also of numerous bioactive/phytonutrient compounds, viz., isoflavones, saponins, protease inhibitors, and phytic acid. These phytonutrients are proven to be beneficial in the prevention and/or treatment of numerous diseases or physiological disorders by exerting antioxidant, hypolipidemic, antiallergic, anti-spasmodic, anti-microbial, hypotensive, and anti-inflammatory effects (Burssens et al. 2011; Gupta and Prakash 2014).

1.3.6.1 Phytate

Phytate [inositol hexaphosphate (IP6)] is the storage form of phosphorus and a natural plant antioxidant in leguminous seeds like soybean. However, it reduces not only the bioavailability of phosphorus, zinc, magnesium, calcium, potassium, and iron (Davidsson et al. 1994; Hurrell 2003) but also the bioavailability of protein and carbohydrates by decreasing the enzymatic activity of pepsin, trypsin, and amylase (Sebastian et al. 1998; Selle et al. 2000).

Nevertheless, through numerous scientific studies, phytate has demonstrated its role as a bioactive agent and holds a great promise in cancer treatments. Phytic acid intake helps in reducing the blood glucose and cholesterol levels (Lee et al. 2006; Lee et al. 2007); increases bone mineral density (López-González et al. 2008); inhibits the crystallization of calcium salts, thus avoiding kidney stone formation (Grases et al. 2000); exerts protective effect in Parkinson's by avoiding excess iron accumulation (Xu et al. 2008); inhibits iron-mediated lipid peroxidation and Fenton oxidative reaction (Graf and Eaton 1990; Rimbach and Pallauf 1998); reduces cell proliferation; and induces differentiation of malignant cells, thus controlling tumor growth, progression, and metastasis (Shamsuddin 2002; Vucenik and Shamsuddin 2004).

Soybean and its products contain almost 1–1.5 g phytic acid/100 g of dry matter (Mikić et al. 2009; Agarwal 2014; Yasothai 2016). Liener (2000) reported that almost two-thirds of the phosphorus in soybean is bound as phytate and unavailable to animals. Several studies have thus been carried out to observe the effects of processing methods on the phytate content of soybean, and it was reported that sprouting, roasting, and pressure cooking lead to a 32%, 88%, and 55% decrease, respectively (Pele et al. 2016; Agarwal 2014). Also, research work is being carried out to develop low phytic acid content in soybean genotypes with better yield and seed viability (Spear and Fehr 2007).

1.3.6.2 Protease Inhibitors

Antiproteolytic substances were first noted by Read and Haas (1938), and since then numerous studies have been undertaken either to estimate the soybean protease inhibitors (SBPI) or to evaluate their antinutritional and health-promoting effects. However, two major forms of SBPI present in soybeans, namely, Kunitz trypsin inhibitor (KTI) and Bowman-Birk inhibitor (BBI), represent 6% of the protein present in soybean seed. It is reported that KTI inhibits trypsin, whereas, BBI affects the enzymatic activity of both trypsin and chymotrypsin, and thus, decreases the biological quality of the soy proteins (Lajolo and Genovese 2002). Also, KTI reportedly leads to hypersecretion of pancreatic enzymes leading to hypertrophy and hyperplasia, and thus, raw soybean is recommended not to be fed to monogastric animals (Kassell 1970; Rackis and Gumbmann 1981; Birk 1985; DiPietro and Liener 1989; Werner and Wemmer 1992). On the contrary, recent research suggests that BBI concentrate (BBIC) can be used as a potential cancer chemopreventive agent and can prevent the development of coronary diseases in humans without toxicity (Kennedy 1998; Dia et al. 2008).

Just like the nutritional attributes, antinutrient and phytonutrient composition is also affected by various genetic and environmental factors. Consequently different authors have reported different values for trypsin inhibitor in soybean seeds. Esteves et al. (2010) pointed out that per gram of soy protein comprises between 30 and

125 mg trypsin inhibitors. De Toledo et al. (2007) found it ranging between 42.6 and 71.6 UTI/mg; Carvalho et al. (2002) reported much higher concentration, i.e., 122–206 UTI/mg; and Gu et al. (2010) observed that trypsin inhibitors range from 3000 to 6000 mg/100 g of raw soybean grain samples.

1.3.6.3 Lectins

Lectins (hemagglutinin or agglutinin) are the carbohydrate-binding proteins which are resistant to digestion and are often considered one of the most toxic constituents of the pulses/beans. Lectins possess high affinity to cellular and intracellular membrane-associated carbohydrates (glycoprotein and glycolipids) [especially N-acetyl-D-galactosamine] and thus, by binding, not only reduce their absorption but can even lead to agglutination of red blood cells, leading to hemolytic anemia (Liener 1994), impairment of the key enzymes of metabolism, and growth retardation, and if administered orally or intraperitoneally can even lead to death (Grant et al. 1988). Numerous studies suggest that lectin consumption can also cause the atrophy of microvilli, intestinal epithelial injury, diarrhea, increased intestinal permeability, and increased proliferation of pathogenic bacteria in the gut (Grant et al. 1995; Pusztai et al. 1991; Pusztai et al. 1995; Machado et al. 2008).

However, recent research suggests that lectins have potent in vivo biological activities and exhibit anticarcinogenic and antitumor activity by either reduction of cell proliferation, induction of tumor-specific cytotoxicity of macrophages, or by having a strong effect on the immune system by production of various interleukins (de Mejia et al. 2003; de lumen 2005). Soybean seeds contain 300–600 mg/100 g lectin (Gu et al. 2010), and approximately 6.5 g lectin/kg is reported in defatted soy meal (Vasconcelos et al. 2001) and approx. 0.2–2% of the soybean protein mass (de Mejia et al. 2003; Rizzi et al. 2003; Anta et al. 2010). Treatments like soaking (Hernandez-Infante et al. 1998), heat treatment, and fractionation during food processing have been reported to be efficient in eliminating lectins and abolishing its hemagglutinating activity, thus improving the nutritional quality of soybeans (Vasconcelos et al. 1997).

1.3.6.4 Oxalate

Oxalate, the simplest dicarboxylic acid is synthesized by the body or absorbed from the gut. It cannot be further metabolized by human beings and must be excreted in the urine (Massey et al. 1993). Oxalate inhibits calcium absorption in the kidneys and increases the risk of developing kidney stones, renal edema, and calcification along with mineral deficiency (Al-Wahsh et al. 2005; Horner et al. 2005). American Dietetic Association categorizes foods containing more than 10 mg oxalate per serving as high-oxalate foods (Al-Wahsh et al. 2005). Soybeans contain moderate amount ranging between 0.67 and 3.5 g oxalate per 100 g (dry weight) (Massey et al. 2001; Horner et al. 2005), which is much lower than the classic high-oxalate foods like spinach (1145 mg/100 g) and chocolate (155–485 mg/100 g dry matter) (Massey et al. 1993) but raises concern over its consumption. Al-Wahsh and authors reported 2–58 mg oxalate per serving in 40 soy foods. Soy flour, textured vegetable soy protein, roasted soybeans, soy nuts, tempeh, and soya butter reportedly had higher than 10 mg oxalate per serving and, thus, come under high-oxalate foods (Al-Wahsh et al. 2005; Massey et al. 2001). However, domestic processing methods like salt treatment, roasting, etc. can help decreasing the oxalate content up to 40% and 20%, respectively (Maidala et al. 2013), and can help in efficient nutrient utilization.

1.3.6.5 Phenolics

Decreased incidence of cardiovascular diseases and different types of cancer in Asian population vis-à-vis Europeans and Americans drove scientists to search for valid reasons behind and reported the intake of soybeans as the significant factor. More comprehensive studies made an observation that the polyphenolic compounds present in soy which also possess estrogenic activity could be the contributing factors (Lampe 2003). De Toledo et al. (2007) observed phenolic compounds and tannin concentration in the range between 6.60 and 8.07 mg/g and 0.28 and 0.39 mg/g, respectively, in different soybean cultivars.

1.3.6.6 Isoflavones

Among all the other flavonoids present in legumes, isoflavones are the major ones in soybeans and occur as β-glucosides (30–35%; genistin, daidzin, and glycitin), aglycones (4–12%; daidzein, genistein, and glycitein), 6″-*O*-acetyl-β-glucosides (0–5%), 6″-*O*-malonyl-β-glucosides (50–65%), and 4′-methyl ethers of daidzein and genistein, formononetin, and biochanin A (Franke et al. 1999; Genovese et al. 2006; Villares et al. 2011). Whole soy contains approx. 50–450 mg/100 g dried weight of total isoflavones (Kim et al. 2006; Ciabotti et al. 2016) with majority (80–90%) of total seed isoflavones concentrated in the cotyledons (Tsukamoto et al. 1995). Soy isoflavones have been reported to reduce cholesterol levels and, thus, risk of cardiovascular diseases (Rivas et al. 2002; Wiseman et al. 2000; Harland and Haffner 2008); inhibit cell proliferation; and have, thus, anticancer property (Shu et al. 2001; Lamartiniere et al. 2000; Jayachandran and Xu 2019) in addition to antioxidant (Lee et al. 2008), anti-aging (Oyama et al. 2012; Kim et al. 2015), anti-inflammatory (García-Lafuente et al. 2009), and antiallergic properties (Masilamani et al. 2011).

1.3.6.7 Saponins

Saponins, the triterpenes, or steroid aglycones (sapogenin) with one or more sugar chains occur in a wide variety of plants. Soybeans are the prime dietary source of saponins and are often referred to soyasaponins. Soyasaponins are usually concentrated in the hypocotyl of the seed, and the total value ranges between 140 and 975 mg/100 g dried weight of the seeds (Fenwick and Oakenfull 1981; Lin and Wang 2004). On the basis of chemical structure, they are classified into three groups, viz., soyasapogenol A (hydroxyl group at the C-21 position), soyasapogenol B (hydrogen atom at the C-21 position), and soyasapogenol E (carbonyl group at C-22 and are oxidation products from group B) (Yoshiki et al. 1998). They impart bitter taste, astringency, foaming properties, and hemolytic activity to the plant material (Ridout et al. 1988 and, thus, were once considered as antinutrients.

However, research has established that soyasaponins are not only safe to be used as food and feed (Ishaaya et al. 1969) but also possess plethora of health benefits, viz., hypocholesterolemic (Chávez-Santoscoy et al. 2013), immune-modulatory (Sun et al. 2014; Qiao et al. 2014), anti-inflammatory (Francis et al. 2002; Mudryj et al. 2014), antiobesity (Kim et al. 2014), hepatoprotective (Kuzuhara et al. 2000), anticarcinogenic (Gurfinkel and Rao 2003; Du et al. 2014), and antimutagenic (Berhow et al. 2002) activities.

1.4 Health Attributes

Numerous epidemiological studies have established that consumption of soybean and its various phytonutrients aids in the prevention and treatment of cancer, cardiovascular disease, and metabolic, musculoskeletal, gynecological, endocrine, and renal outcomes especially in perimenopausal women (Li et al. 2019; Watanabe and Uehara 2019; Abo-Elsoud et al. 2019; Latorraca et al. 2019). Detailed information on dosage, route of administration, the model used, and the results based on the experimental research study both in vitro and in vivo are depicted in Table 1.3.

1.4.1 In Hyperglycemia

Numerous animal and human studies have reported the antidiabetic potential of soybean and its bioactive components (soy isoflavones, protein, fiber, saponins, etc.) by regulating blood glucose levels and improving insulin resistance and kidney filtration (Holt et al. 1996; Chandalia et al. 2000; Jenkins et al. 2003a, b; Trujillo et al. 2005; Azadbakht et al. 2007; Pipe et al. 2009; Kwon et al. 2010; Chalvon-Demersay et al. 2017). In a recent study, Tatsumi et al. (2013) reported lower type 2 diabetes incidence in Japanese men with BMI >23.6 kg/m^2 on consumption of ≥ 4 servings/week of soybean products.

Table 1.3 Summary of numerous in vivo and in vitro studies indicating health effects of soybean and its bioactive components

Experimental model	The form of soya bean	Dose and route of administration	Investigation	Major finding/s	Reference
Human (DM patients)	Roasted soya bean powder	69 g/d for 4 weeks	Assay of glycemic control and lipid metabolism parameters	Hypolipidemic, hypoglycemic, and antioxidant activity	Chang et al. (2008)
Sprague-Dawley rats	Isolated soy protein (ISP) and genistein	STZ-genistein, 600 mg/kg diet, and STZ-ISP, 200 g/kg diet for 3 weeks	Assay of blood glucose, lipid metabolism parameters, and antioxidant enzymes	Hypolipidemic, hypoglycemic, and antioxidant activity	Lee (2006)
Human (DM patients)	Soy-based dietary supplement	Abalon (50 g soy protein, 165 mg isoflavones, and 20 g cotyledon fiber)/day for 6 weeks	Assay of blood glucose, lipid metabolism parameters	Hypolipidemic	Hermansen et al. (2001)
Human (hypercholesterolemic patients)	Soy-based dietary supplement	Abalon (30 g soy protein, 9 g cotyledon fiber, and 100 mg isoflavones)/day for 24 weeks	Assay of LDL cholesterol and other cardiovascular risk factors (including endothelial function)	Hypolipidemic	Hermansen et al. (2005)
Human (postmenopausal diabetic women)	Phytoestrogens	Phytoestrogens (soy protein 30 g/d, isoflavones 132 mg/d)/day for 12 weeks	Assay of glycemic control and cardiovascular risk markers	Hypolipidemic, hypoglycemic, and cardioprotective effect	Jayagopal et al. (2002)
Human (diabetic women)	Soy isoflavones	435 mg/d for 2 months	Assay of blood glucose, lipid metabolism parameters	Hypolipidemic and reduced risk of diabetes	Chi et al. (2016)
Human (obese diabetic patients)	Soy-based meal replacement (MR) plan	12 months	Assay of weight loss and metabolic profile	Weight reduction and hypoglycemic effect	Li et al. (2005)
Human (postmenopausal women)	Soy isoflavones	40–80 mg/d for 1 year	Assay of blood glucose, lipid metabolism parameters	Hypoglycemic	Ho et al. (2007a, b)

Human (DM patients)	Soy protein isolate (SPI)	80 mg/d for 57 d	Assay of lipid metabolism parameters	Hypolipidemic and cardioprotective effect	Pipe et al. (2009)
Human	Soy protein isolate (SPI)	Low-isoflavone SPI (1.64 ± 0.19 mg/d) and high-isoflavone SPI (61.7 ± 7.4 mg/d) for 57 d	Assay of lipid metabolism parameters	Hypolipidemic and cardioprotective effect	McVeigh et al. (2006)
Human (hyperlipidemic and diabetic patients)	Soya bean dietary supplement	D-LeciVita (12% lecithin, 35% soy protein) 15 g/d for 12 weeks	Assay of blood glucose, lipid metabolism parameters	Hypolipidemic and cardioprotective effect	Medić et al. (2006)
Human (men and Postmenopausal women)	Soy protein isolate (SPI)	SPI (40 g soy protein, 118 mg isoflavones)/d for 3 months	Assay of blood pressure and lipid metabolism parameters	Improvement in blood pressure and hypolipidemic effect	Liang et al. (2006)
Human (hyperlipidemic)	Soybean product diet	2%/d for 4 weeks	Assay of blood pressure and lipid metabolism parameters	Hypolipidemic and cardioprotective effect	Kurowska et al. (1997)
Human (hypercholesterolemic renal transplant recipients)	Soy protein diet	25 g soy protein/day for 5 week	Assay of blood lipid metabolism parameters	Hypolipidemic	Cupisti et al. (2004)
Human (obese)	Soy-based low-calorie diet	Soy protein (only protein source) for 8 weeks	Assay of weight control, body composition, and blood lipid profile	Weight and body fat reduction along with hypolipidemic effect	Liao et al. (2007)
Human (hypercholesterolemic)	Isolated soy protein (ISP)	30–50 g ISP and 10–16.6 g cotyledon fiber/d for 16 weeks	Assay of lipid, lipoprotein, and homocysteine concentrations	Hypolipidemic and antiatherosclerotic effect	Tonstad et al. (2002)
Human (postmenopausal)	Soy protein isolate (SPI)	SPI (40 g/d) for 6 weeks	Assay of weight control, body composition, and blood lipid profile	Hypolipidemic and cardioprotective effect	Hanson et al. (2006)
Human (diabetics)	Soy nut diet	60 g/d for 8 weeks	Assay of blood glucose, lipid parameters, and antioxidant enzymes	Hypolipidemic, hypoglycemic, and cardioprotective effect	Sedaghat et al. (2019)

(continued)

Table 1.3 (continued)

Experimental model	The form of soya bean	Dose and route of administration	Investigation	Major finding/s	Reference
Sprague-Dawley rats	Phenolic-rich soy husk powder extract (SHPE)	250 mg SHPE/kg BW or 500 mg SHPE/kg BW	Assay of blood glucose, lipid metabolism parameters	Hypoglycemic and antiadipogenic	Tan et al. (2019)
Human (diabetic)	Soy protein with or without isoflavones (SPI, SP)	7.5 g (15 g daily) of 70% isolated soy protein powder with or without added isoflavones (Solgen 16 mg per bar, 32 mg in total daily) for 8 weeks	Assay of blood glucose, lipid metabolism parameters	Weight and body fat reduction along with hypolipidemic effect	Konya et al. (2019)
Goto-Kakizaki rats	Soy isoflavones (SIF)	SIF (150 mg/kg BW) for 16 weeks	Assay of blood glucose, lipid metabolism parameters	Hypoglycemic	Jin et al. (2018)
Wistar rats	Soy isoflavones	80 mg/kg BW/d for 4 weeks	Assay of plasma insulin, blood glucose, and hepatic glycogen	Antidiabetic and hypolipidemic	Hamden et al. (2011)
In vitro		–	Analysis of insulino-secretory effect of isoflavones and α-amylase inhibitory activity		
Sprague-Dawley rats	Soy hull soluble dietary fiber (SHSDF)	4% of SHSDF for 4 weeks	Hypocholesterolemic Activity assay	Hypocholesterolemic	Liu et al. (2016)
In vitro		–	Assay of in vitro cholesterol-binding capacity, bile acid-binding capacity, and glucose dialysis retardation index		
Sprague-Dawley rats	Soy isoflavones	0.2% soy isoflavones rich powder for 5 weeks	Assay of blood lipid parameters and antioxidant enzymes	Antioxidant and hypocholesterolemic	Kawakami et al. (2004)
Wistar adult rats	Soybean β-conglycinin (>90% protein, 0.4% isoflavone, and 0.2% saponin)	20% soybean β-conglycinin for 4 weeks	Assay of carbohydrate and lipid metabolism parameters	Hypolipidemic	Inoue et al. (2015)

Human (hyperlipidemic)	Soy protein-based cookies	30 g/d for 5 months	Assay of blood glucose, lipid metabolism parameters	Hypolipidemic	Borodin et al. (2009)
Hamsters	Soy pinitol	Pinitol supplementation (0.05% P-I and 0.1% pinitol, P-II) with an HFHC diet (10% coconut oil plus 0.2% cholesterol) for 10 weeks	Assay of blood glucose, lipid metabolism parameters	Lipid-lowering, anti-oxidant, and hepatoprotective effects	Choi et al. (2009)
Sprague-Dawley rats	Non-dialyzed soybean protein hydrolysate (NSPH)	14.7% casein +5% NSPH for 12 weeks	Assay of plasma and liver lipid profiles	Hypolipidemic	Yang et al. (2007)
New Zealand male rabbits	Soy isoflavones	0.73 or 7.3 mg of isoflavones/kg/day for 180 d	Assay of blood lipid metabolism parameters	Atheroprotective	Damasceno et al. (2007)
New Zealand white rabbits	Soy isoflavones	2.5 or 5 mg/kg B.W. doses of isoflavones for 13 weeks	Assay of blood glucose, lipid parameters, and antioxidant enzymes	Hypolipidemic and antioxidant activity	Yousef et al. (2004)
Sprague-Dawley rats	Soy protein isolate (SPI)	195 g/kg SPI protein/d for 6 weeks	Bone analyses, serum bone turnover markers, and NEFAs estimation	Bone-protective effect	Chen et al. (2013)
Rattus norvegicus albinus	Soy isoflavones (ISO)	ISO (150 mg/kg by gavage) for 30 d	Assay of collagen I (ColI) and sulfated glycosaminoglycans (GAGs) in the bone matrix	Decreased bone loss	Carbonel et al. (2019)
Human (postmenopausal women)	Soy product	–	Estimation of intake of soy products, folate, methionine, and vitamins B-6 and B-12 by a semiquantitative food frequency questionnaire	Favorable effect on homocysteine metabolism	Nagata et al. (2003)
Human (prostate cancer)	Soy bread	2 slices/d (60 mg aglycone equivalents of isoflavones/day) for 8 weeks	Evaluation of plasma isoflavonoids and isoflavonoids in urine	Cancer-protective effect	Ahn-Jarvis et al. (2015)

(continued)

Table 1.3 (continued)

Experimental model	The form of soya bean	Dose and route of administration	Investigation	Major finding/s	Reference
Prostate cancer cells (PC3 and DU145)	D-Pinitol	(0, 1, 3, 10, and 30 μM) for 24 h,	Assay of cell viability, TUNEL, caspase 3 activity, migration and invasion, and wound-healing migration	Reduced metastatic activity of human prostate cancer cells	Lin et al. (2013)
C57BL/6 × FVB F_1 TRAMP male pups	Soy isoflavone	–	Assay of hepatic aromatase and 5α-reductase; expression of AR, AR-regulated genes, FOXA1, UGT weight, and tumor progression; and upregulated protective FOXO3	Chemopreventive	Christensen et al. (2013)
Transgenic adenocarcinoma of the mouse prostate (TRAMP) model	Soy germ powder and tomato powder	2% soy germ (SG) powder or 10% tomato powder with 2% soy germ powder (TP + SG) for 14 weeks	Assay of isoflavone and carotenoid analysis in serum, prostate, and tissues	Prostate cancer-preventive effect	Zuniga et al. (2013)
LNCaP and C4-2B cells	Cooked and in vitro digested soy extracts	500,1000, and 2000 μg/mL	Apoptosis and cytotoxicity assays	Anticancer effect	Dong et al. (2012)
BALB/c mice (4T1 breast tumor model)	Soy isoflavone	100 mg/kg diet	Analysis of NF-κBp65′ vascular endothelial growth factor receptor 2 (VEGFR2) and Pgp gene and protein expressions	Anticarcinogenic effects	Hejazi et al. (2017)

A diet high in fiber, especially soluble fiber, can reduce the carbohydrate absorption rate and, hence, decrease the plasma glucose concentration in diabetic patients (Messina 1999; Chandalia et al. 2000). Similarly, another studies showed that intake of soybean dietary fiber increased fecal bile excretion, thus decreased fat absorption (Jenkins et al. 2003a, b), and, hence, a protective effect on hyperglycemia. Liu et al. (2016) reported that the physicochemical properties and in vitro binding capacity of soluble fibers extracted from soy hulls are similar to oat β-glucan which possesses proven glucose- and cholesterol-lowering properties.

Lee (2006) investigated the effect of soy protein and genistein on the blood glucose, lipid profile, and antioxidant enzyme activities in streptozotocin-induced diabetic Sprague-Dawley rats. The results implicated the beneficial role of soy protein and genistein in diabetes as their supplementation not only increased the glucokinase level, hepatic superoxide dismutase, catalase, and glutathione peroxidase activities but also decreased the HbA1c level of the STZ-induced diabetic rats. Ascencio et al. (2004) reported that the soy protein intake not only decreases the accumulation of triglycerides in the liver but also reduces the damaging effects of lipotoxicity in the liver, which had been recognized as the primary cause of obesity and related disorders, viz., insulin resistance, heart failure, and type 2 diabetes (Unger 2003; Sharma et al. 2004). In addition, soy protein intake in diabetic and non-diabetic patients has been reported to reduce the kidney damage and inflammation by reducing glomerular-filtration rate and improving creatinine clearance and, thus, holds the potential to be used as a therapeutic agent in the chronic kidney diseases (Azadbakht et al. 2003; Teixeira et al. 2004; Stephenson et al. 2005).

Recently, soy isoflavones especially daidzein, commonly found in fermented soybeans, have been reported to be beneficial in the therapeutic management of type 2 diabetes (Usui et al. 2013). Several in vitro studies have examined the antidiabetic and hypoglycemic effects and observed a dose-dependent effect of daidzein on intracellular glucose uptake in absence of insulin (Cheong et al. 2014) and inhibitory effect on α-glucosidase and α-amylase activities (Choi et al. 2010) and on the mRNA expression of CCL2 and IL6 (pro-inflammatory cytokines) in the adipocytes (Sakamoto et al. 2016). Also, its supplementation in the lean mice diet led not only to an increased glucose uptake but also glycogen synthesis in the liver, heart, and red blood cells (Meezan et al. 2005). Several clinical studies have also established the role of daidzein and its metabolite equol in the treatment of type 2 diabetes (Ho et al. 2007a, b; Villegas et al. 2008; Nguyen et al. 2017).

Lu et al. (2012) have reported the antidiabetic potential of aglycin, a bioactive peptide isolated from soybeans, in diabetic BALB/c mice. The authors reported that by increasing insulin receptor signalling pathway in the skeletal muscle, aglycin controlled hyperglycemia and improved oral glucose tolerance in the diabetic mice. Sivakumar and Subramanian (2009) investigated the effect of D-pinitol, a bioactive component isolated from soybeans, in diabetic rats, and observed that it alters the activities of key hepatic enzymes involved in carbohydrate metabolism and, thus, attenuates the hyperglycemic effect in diabetic rats. Soyasaponins have also been reported to possess hypoglycemic effect by exerting inhibitory effect on α-glucosidase enzyme (Quan et al. 2003). A more recent in vitro and in vivo study by Wang et al. (2017) suggests that stigmasterol (phytosterol derived from soybean oil) has potential therapeutic effect in type 2 diabetes. In the in vitro study, stigmasterol exhibited a mild GLUT4 translocation activity and enhanced glucose uptake in L6 cells. Furthermore, when stigmasterol was orally administered to KK-Ay mice, it led not only to a significant reduction in the fasting blood glucose level, triglyceride, and cholesterol but also an improvement in insulin resistance and oral glucose tolerance.

1.4.2 In Cardiovascular Diseases

Several epidemiological studies have investigated the role of soybean in the incidence of cardiovascular disease and have reported an inverse relationship owing to the presence of soy proteins (Torres et al. 2006), bioactive peptides (Friedman and Brandon 2001; Choi et al. 2002), soy isoflavones (Nagata et al. 2016; Liu et al. 2014), polyphenols (Huang et al. 2016a, b), phospholipids (Sahebkar 2013), stanols and lecithins (Spilburg et al. 2003), and soy phytosterols (Anderson et al. 1995; Ostlund Jr 2004; Escurriol et al. 2010; Genser et al. 2012).

Shimazu et al. (2007) reported an inverse association between soybean intake and CVD mortality. A meta-analysis of randomized controlled trials by Tokede et al. (2015) also found that soy product intake led to a significant decrease in total cholesterol, LDL-C, HDL-C, and triglycerides. However, interestingly Nagata et al. (2016) observed that different soy foods may present different biological efficacy and protective effects.

Cholesterol-lowering effect of soy protein was first studied in 1967 (Hodges et al. 1967), and since then, numerous epidemiological surveys and nutritional interventions have suggested the possible cardioprotective role of soy proteins (Radcliffe and Czajka-Narins 1998; Jenkins et al. 2003a, b; Merritt 2004; Anderson and Bush 2011; Zhan and Ho 2005). Homocysteine (Hcy) is one of the risk factors for cardiovascular diseases, and since methionine is a precursor of Hcy, hence, the intake of soy protein which is low in methionine helps in reducing the coronary heart disease risk (Tovar et al. 2002). Schmitt et al. (1998) reported that high ratio of insulin/glucagon is positively associated with hyperlipidemic and atherogenic effects and long-term soy protein intake reduces the insulin/glucagon ratio and, hence, exhibits hypolipidemic effect. β-Conglycinin, a bioactive peptide present in soybean, has been reported to possess greater cholesterol- and triglyceride-lowering effects when compared with soy protein isolate (Bringe 2001) owing to the decreased intestinal cholesterol absorption, bile acid uptake (Nagaoka et al. 1999), reduced aortic accumulation of cholesteryl esters (Adams et al. 2004), and increased cholecystokinin levels which suppress food intake and gastric emptying (Nishi et al. 2003).

It is believed that soy isoflavones by activating the estrogen receptors and intracellular kinase signalling cascades exert anti-inflammatory responses and modulate the vascular reactivity (Li et al. 2006) and could lower the bile acid synthesis, hepatic lipid synthesis, and cholesterol reabsorption (Ricketts et al. 2005). However, recent studies like that of Engelbert et al. (2016) and Taku et al. (2008), wherein no significant changes in the total cholesterol were reported in postmenopausal women taking isoflavone supplements/extracts, have led to a wide disagreement regarding the hypolipidemic role of soy isoflavones. Moreover, recent research suggests that a synergistic interaction of soy isoflavones and soy protein augments the blood lipid profile and, hence, exerts hypolipidemic effect (Xiao et al. 2014; Kobayashi et al. 2014).

1.4.3 In Hypertension

Soybean and its bioactive components (soy protein, isoflavones, etc.) have been reported to mitigate hypertension by mechanisms involving vasodilation and inhibition of key enzyme involved in the blood pressure regulation (Jackson et al. 2011). In the postmenopausal pre-diabetic hypertensive women, soy protein and isoflavone intake attenuated the blood pressure (Welty et al. 2007; Liu et al. 2013). Colacurci et al. (2005) studied the effect of isoflavone supplementation in postmenopausal women for 6 months and reported improvement in endothelial vasodilation along with reduction in cellular adhesion molecules. However, other studies have found that soy isoflavone supplementation can exert hypotensive effect in hypertensive but not in normotensive adults (Taku et al. 2010; Patten et al. 2016). Since soybean is a rich source of arginine which in turn is a precursor to nitric oxide in the L-arginine pathway, thus, it improves endothelial function and demonstrates hypotensive effect (Bai et al. 2009; Dong et al. 2011). Also, in vitro studies have showed that soy pulp containing oligopeptides and fiber in high amounts exhibited anti-angiotensin-converting enzyme activity and, hence, hypotensive effect (Nishibori et al. 2017).

1.4.4 In Obesity

Overweight and obesity have a profound impact on global health, and it is a risk factor for several chronic diseases like diabetes and hypertension. Epidemiological evidence suggests a positive association between soy consumption and weight management by enhancing insulin resistance and subsiding lipoprotein lipase activity (Velasquez and Bhathena 2007; Ørgaard and Jensen 2008; Muscogiuri et al. 2016).

Kurrat et al. (2015) reported that lifelong intake of soy isoflavones reduced the body weight, serum leptin, and visceral fat mass and resulted in smaller adipocytes in female Wistar rats. In another study, diet-induced obese male rats when fed with soy isoflavones showed enhanced lipolysis and β-oxidation along with suppressed lipogenesis, adipogenesis, and decreased body weight (Huang et al. 2016a, b). However, some studies have also reported that soy isoflavone supplementation resulted in increased adipose tissue (Zanella et al. 2015), increased total cholesterol, and leptin concentrations in mice (Giordano et al. 2015).

Since soy protein is a major constituent and possesses high biological value in addition to the presence of bioactive compounds, its role in obesity cannot be overlooked. Soy protein isolate and its hydrolysate were found to be effective in reducing the body fat and perirenal fat pads when compared with whey protein isolate in the treatment of obese male Sprague-Dawley rats (Aoyama et al. 2000). Nagasawa et al. (2002) observed decreased body fat content and plasma glucose levels in obese mice fed with soy protein than the mice fed with casein protein diet. Anderson and Hoie (2005) investigated the effects of soy- versus milk-based meal replacement in obese women (BMI: 27–40 kg/m^2) for 12 weeks and reported modest weight loss coupled with significant reduction in blood lipids of the subjects. Neacsu et al. (2014) in a randomized crossover trial reported appetite control and weight loss among obese men fed with soy-based high-protein weight-loss diets.

1.4.5 In Inflammation

Han et al. (2015) suggested the anti-inflammatory effect of genistein (a soy isoflavone) in homocysteine (Hcy)-induced endothelial cell inflammatory injury. It is reported that soy isoflavones exhibited the anti-inflammatory effects by showing a reduction in the release of reactive oxygen species (ROS), inhibited NF-kB activation; down-regulating the expression of cytokine IL-6 and adhesion molecules ICAM-1, avoiding inflammatory cells and platelet adhesion, and thus, balanced the endothelial cell proliferation and apoptosis. Sakamoto et al. (2016) concluded from their in vitro study that daidzein or soy consumption can be helpful in suppressing chronic inflammation which in turn can alleviate obesity-related insulin resistance. Wang and Wu (2017) reported that dietary soy isoflavones hold the potential to alleviate dextran sulfate sodium (DSS)-induced inflammation in mice by enhancing antioxidant function and inhibiting the TLR4/MyD88 signal.

1.4.6 Effects on Menopausal Symptoms

Since 1991, several studies have been undertaken to investigate the role of soybeans and its bioactive components on the menopausal symptoms and have reported their efficacy in the same (Lockley 1991; Adlercreutz et al. 1992; Murkies et al. 1995; Lethaby et al. 2007; Howes et al. 2006). However, Newton and Grady (2011) have commented that the results may have been misinterpreted, and Messina (2014) observed that the studies did not sub-analyze the data according to the isoflavone profile of the intervention product. Recently, Furlong et al. (2019) investigated the effects of a commercially available soy drink containing 10–60 mg/d dose of isoflavones for 12 weeks on the cognitive function and menopausal symptoms in postmenopausal women. The authors reported no change in the cognitive function but significant reduction in the vasomotor symptoms in subjects with severe symptoms at baseline.

1.4.7 In Bone Health

Zhang et al. (2005) conducted a prospective cohort study in Shanghai to investigate the efficacy of soy food consumption among 24,403 postmenopausal women, and the results revealed that consumption of soy protein (>10 g/d) was associated with almost one-third reduction in the fracture risk in the subjects. Similar results were reported in the postmenopausal women participating in the Singaporean study wherein 63,257 Chinese adults (45–72 years) were studied. However, Levis et al. (2011) and Tai et al. (2012) did not find any positive effect.

1.4.8 Anticarcinogenic Activities

Numerous experimental models have revealed the anticancer activity of soy-based diets and its bioactive compounds (Zhou et al. 1999; Mentor-Marcel et al. 2001; Trottier et al. 2010; Zuniga et al. 2013). The consumption of foods rich in soy isoflavones is associated with reduction in the occurrence and mortality of breast cancer (Valachovicova et al. 2004; He and Chen 2013; Applegate et al. 2018). Applegate et al. (2018) conducted a meta-analysis and reported that soy foods and their isoflavones (genistein and daidzein) resulted in the reduction of prostate cancer (PCa) risk. Soy isoflavones are assumed to effect PCa aggression through various pathways such as inhibition of tumor growth factor signalling (Wang et al. 2003), cell cycle inhibition (Zhou et al. 1999), metastasis (Pavese et al. 2014), and anti-angiogenesis (Fotsis et al. 1993; Guo et al. 2007). Yu et al. (2016) performed a meta-analysis of 17 epidemiological studies consisting of 13 case controls and 4 prospective cohort studies to investigate the association between colorectal cancer (CRC) risk and soy isoflavone consumption in humans. The study revealed that intake of soy foods containing soy isoflavones by Asian population in the case-control studies resulted in a decreased CRC risk. It is believed that soy isoflavones can exert the antitumor effects via their roles in antioxidation, DNA repair, antagonism of estrogen- and androgen-mediated signalling pathways, inhibition of angiogenesis and metastasis, and potentiation of radio- and chemotherapeutic agents (Bilir et al. 2017; Mahmoud et al. 2014).

As discussed above the consumption of soy products rich in isoflavones has been associated with decreased cancer risks, but in the recent times, some studies have raised concerns on the deleterious health effects of isoflavones, predominantly on the carcinogenic activity (Poschner et al. 2017; Wei et al. 2015; Andrade et al. 2015; Shike et al. 2014) and reproductive toxicity (Patel et al. 2016; Chinigarzadeh et al. 2017), adverse effects on growth and development (Harlid et al. 2016; Yin et al. 2014; D'Aloisio et al. 2013), and impacts on immune functioning (Wynn et al. 2013; Gaffer et al. 2018).

A recent study suggests that soyasapogenol B (Soy B) through inducing apoptotic and autophagic cell death, thus, attenuates laryngeal carcinoma progression in human laryngeal carcinoma cell lines HeP-2 and TU212 (Zhi et al. 2019). Wang et al. (2019) investigated the effect of Soy B in the prevention and treatment of CRC; and reported that it promoted apoptosis and autophagy in both in vitro and in vivo assays, by triggering endoplasmic reticulum stress, and, hence, can be utilized as a chemotherapeutic agent in CRC.

Since Liener (1991) reported that soybean agglutinin holds the potential to inhibit the growth of transplanted tumor in rats, numerous studies have established the possible antitumor and anticarcinogenic potential of plant lectins (Suzuki et al. 1999; Jakab et al. 2000; Pryme and Bardocz 2001; Evans et al. 2002). Soybean lectins have been found to suppress the tumor growth, Dalton's lymphoma, macrophages, peripheral blood lymphocytes (Ganguly and Das 1994) and cytoagglutination/aggregation in SW 1222 human colon cancer, HT29 human colon cancer (Jordinson et al. 1999), SP2 myeloma; and Lox-2 Ab-producing hybridoma (Takamatsu et al. 1999). Additionally, recent research has pointed out toward a newly discovered soybean peptide, lunasin, as a new and novel cancer chemopreventive agent (de Mejia et al. 2003).

1.5 Food Applications

1.5.1 Soybean Oil

Soybean oil, one of the most consumed edible oils (26.7% of the total), is the largest commercial source of essential fatty acids and is utilized in many food products, viz., as salad and cooking oil, shortening, margarine, mayonnaise, and salad dressing. Its easy availability and functionality coupled with cheap price are the reason behind its massive acceptance as edible oil in the world (Medina-Juarez et al. 1998; List 2016). From the nutritional point of view, it contains linoleic acid (50–60%), oleic acid (22–30%), palmitic acid (7–10%), linolenic acid (5–9%), stearic acid (2–5%), and arachidic acid (1–3%) and polyunsaturated/saturated ratio of 4.1. Apart from this it also contains lecithin (phosphatidylcholine), phospholipids, tocopherols, and phytosterols (Fan and Eskin 2015).

However, high amounts of polyunsaturated acids and omega-3 fatty acids in soybean oil limit its commercial functionality as they present oxidative stability problems and limit the fry life, respectively (List 2016).

1.5.2 Soy Products

1.5.2.1 Soy Protein Products

Cereals form an important source of energy and nutrients in the majority of the world population. However, the low protein quality due to imbalanced amino acid composition is a major concern. Hence, soybean protein in various forms, viz., flour and grits (full fat, medium fat, low fat, defatted, and lecithinated), soy protein concentrate, soy protein isolate, and textured soy protein, is utilized by the food industry for its good-quality protein, low cost, and numerous functional and nutraceutical properties (Kulkarni et al. 1992).The chemical composition of various soy products is depicted in Table 1.4.

1.5.2.2 Soy Flour and Grits

After oil is removed from the soybean, the proteinaceous material left is referred to as soybean flakes which are then ground into flour (100 mesh or finer). Grits are coarser than the flour (>100 mesh). Soy flour and grits are the least refined form and possess varying amount of fat, particle size, texture, saponins and isoflavones which result in the typical beany flavor (Singh et al. 2008). Full-fat soy flour is used in the production of soy milk and tofu and as an economic extender in developing countries for non-fat dry milk in beverages (Ohr 1997) and baked goods (Rakosky 1974). The lipoxidase enzyme-active full-fat soy flour helps in improving the whiteness of bread dough (French 1977), acts as a good emulsifier and stabilizer, and, hence, helps in

Table 1.4 Chemical requirements of soy products

Soy product	Protein (Nx6.25)%	Carbohydrates (%)	Fat (%)	Moisture (%)	Crude fiber (%)	Ash (%)	PDCAAS*
Full-fat soy flour[a]	35–40	20.0	18–20.5	10	4.0	6.5	–
High fat[a]	46	–	14.5	6.0	–	–	–
Low fat[a]	52.5	–	4.0	6.0	–	–	–
Lecithinated[a]	51	–	6.5	7.0	–	–	–
Defatted soy flour[b]	50	20	1.5	9.0	3.5	7.0	0.90
Soy protein concentrate[b]	65	20	1.0	6.0	4.0	6.0	0.95
Soy protein isolates[b]	90	4.0	1.0	6.0	0.2	4.5	0.90
Texturized soy protein[b]	50	20	3.0	10	4.0	6.5	0.90

*PDCAAS: Protein digestibility-corrected amino acid score
[a]Campbell et al. (1985)
[b]ASA (2000)

homogenizing milk in cakes and improves mixing tolerance when mixed with ready flour mixes (Onayemi and Lorenz 1978; Lutzow 1996; Stauffer 2006).

On the other hand, defatted soy flour and grits can be utilized in the fortification of cereals and processed foods like baked goods. Its fortification not only helps in the enhancement of the protein content in the processed foods but also improves the crumb body in the baked foods, enhances shelf life of cookies by reducing the moisture content (Marques et al. 2000), and improves water holding capacity and sheeting properties of the dough, thus resulting in tender finished product (Golbitz 2000). The toasted soy flour and grits are preferred in cookies/crackers, cereal applications (like breads), ground meats, and fermentation media because of their better texture than the untoasted counterparts (Endres 2001; Jideani 2011).

1.5.2.3 Soy Protein Isolates (SPI)

Soy protein isolates are generally made from defatted soy meal and are the most refined form. They should possess good emulsifying capacity, gelling capacity, viscosity, and water and fat absorption to be utilized efficiently in various food systems (Singh et al. 2008). Since, they have a very high protein content (>90%) and are prepared by removing the water-insoluble polysaccharides and oligosaccharides, they do not result in flatulence and have bland flavor. Thus, SPI are ideally suited ingredients in meat systems (due to the mouthfeel and texture); dairy foods as milk replacer, nutritional supplements, and infant formulas; beverages; soups; sauces; snacks; etc. aimed for people having high protein needs owing to various circumstances like growth in children, famine, and chronic diseases, viz., AIDS, tuberculosis, etc. (Singh et al. 2008).

1.5.2.4 Soy Protein Concentrates (SPC)

Soy protein concentrates contain approximately 70% protein and are prepared from the defatted soy flour by removing oligosaccharides, some amount of ash, and other minor components (ASA 2000). The concentration process improves the dispersibility and water and fat holding capacity and improves its flavor profile which modifies the viscosity and textural characteristics of the food system. Hence, SPC are utilized in the production of baby foods, dry food mixes, nutritional powder drinks, emulsion-type meat products, bakery products, milk replacers, snacks, and pet foods (Singh et al. 2008).

1.5.2.5 Textured Soy Protein (TSP)

Textured soy proteins are commercially prepared by the thermoplastic extrusion of soy flour/grits/concentrates under heat and pressure to yield chunks/chips/flakes or any other shape. The high amount of heat and pressure along with extrusion not only increases the water absorption index and water hydration capacity but also hardens and expands the product to impart a fibrous texture (Horan 1974; Grasso et al. 2019; Toldrà et al. 2019) and, thus, be used majorly as meat alternatives (Macedo-Silva et al. 2001; Wong et al. 2019). In the dry form, they are incorporated in the applications wherein during processing the juices liberated by the meats need to be absorbed for a firm final product, for example, beef patties, sausages, pizza toppings, frozen dinners, packaged dinners and soups, taco fillings, vegetarian foods, pet foods, etc. On the other hand, the hydrated forms are handled just like any other meat/perishable food (Lin et al. 2000; Hennenger 2002).

1.5.3 Fermented Soy Foods

The classification of traditional soy products is represented in Fig. 1.4.

1.5.3.1 Soy Sauce

It is a fermented soybean condiment which originated approximately 2500 years ago in China. *Aspergillus oryzae* and/or *Aspergillus sojae* molds are usually used for fermenting soybean paste (Chen et al. 2012). Soy sauce was first used in only

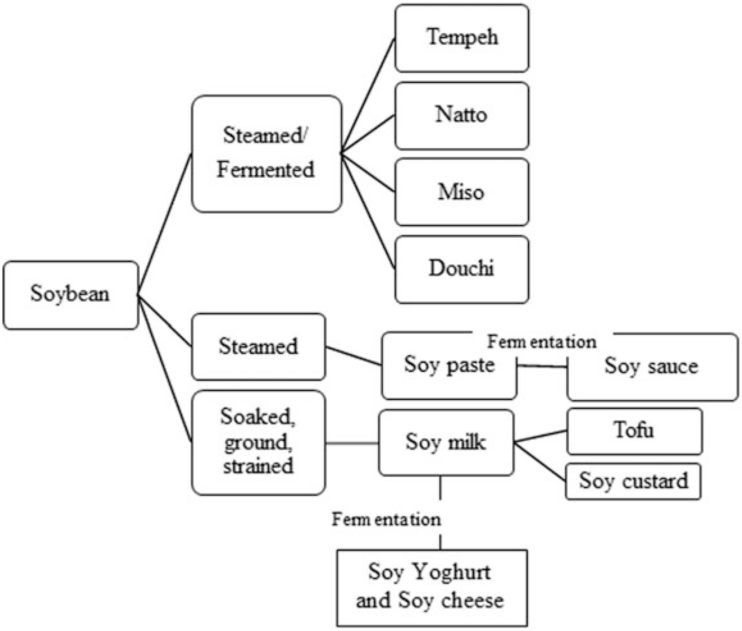

Fig. 1.4 Classification of traditional soybean products

Oriental cuisine but now has gained popularity and is now a major ingredient in American cuisine.

1.5.3.2 Soy Sprouts

Since ancient times, sprouted soybeans have been included in the Korean cuisine as the development of food products from germinated soybeans further increases the versatility and utility owing to it having zero cholesterol, low saturated fatty acid, low calorie, and high fiber content (Hwang 1997; Kwon et al. 2005).

1.5.3.3 Tempeh

Fermentation of whole soybeans along with rice/millets yields a smoky- or nutty-flavored, chunky, and tender soybean cake. This product is called tempeh and is a traditional Indonesian food. It protects against diarrhea and chronic degenerative diseases and, thus, is slowly gaining importance as an important functional food ingredient (Vital et al. 2018).

1.5.3.4 Natto

Natto, a traditional Japanese health food, is prepared by *Bacillus subtilis* var. *natto* (*Bacillus natto*)-fermented whole soybeans and is reported to be having numerous health benefits (Fujiwara et al. 2008).

1.5.3.5 Miso

Miso, a fermented soybean paste, is a healthy Japanese seasoning which has numerous health benefits. In the recent times, owing to its health attributes and superb taste, it is utilized in numerous food applications like soups, sauces, dressings, marinade, and pastes (Mani and Ming 2017).

1.5.4 Non-fermented Soy Foods

1.5.4.1 Soy Milk/Beverages

Soybeans when soaked, ground, and strained yield an aqueous, white, and creamy extract which is similar in appearance and consistency to cow's milk. It is a traditional drink of the Eastern world and can be consumed by lactose-intolerant people (Rivas et al. 2002). It contains nearly 3–4% protein (same as cow milk, although amino acid composition differs), 1.5–2.0% fat, and 8–10% carbohydrates (Kohli et al. 2017). The soy milk serves as a base material for tofu, soy yogurt, custard, cheese, etc. (Favaro Trindade et al. 2001; Liu et al. 2006).

1.5.4.2 Tofu (Soy Paneer)

Tofu is also known as soy curd which is usually served as a dessert and side dish. It is a soft cheese made by curdling the fresh hot soy milk by addition of calcium or magnesium salts. Tofu is a good source of proteins and isoflavones and can be stored up to 1 year under ambient conditions (Chen et al. 2012).

1.5.4.3 Soy Cheese

Soy cheese is made from soy milk. Its creamy texture makes it an easy substitute for animal protein and can be utilized as a low-cost protein source (Ibironke and Alakija 2018).

1.5.4.4 Non-dairy Soy Frozen Dessert

The production of non-dairy frozen desserts is a novel trend in the functional food industry. Soy frozen dessert is made from either soy milk or soy yogurt and is one of the most popular healthy desserts made from soybeans (Atallah and Hassan 2017; Norouzi et al. 2019; Rezaei et al. 2019).

1.5.4.5 Soy Nut Butter

It is made from roasted and crushed whole soybeans which are then blended with soy oil and other ingredients for a creamy and crunchy texture. It is a tasty and healthy alternative to peanut butter and provides 7 g of soy protein per serving. Recently, owing to the risk of the peanut allergies, many schools in the United States are introducing soy nut butter in the school lunch programs (Shurtleff and Aoyagi 2012).

1.5.4.6 Soy Fiber (Okara, Soy Bran)

The solid residue left after the extraction in the production of soy milk or tofu is called okara. It is rich in proteins (24.5–37.5%), fiber (14.5–55.4%), and fats (9.3–22.3%) and has a neutral taste unlike the other soy products. The essential amino acid composition and functional properties like emulsification, foaming, fat binding, and fat absorption capacity are similar to the commercial soy protein isolates, and thus, it holds a great potential to be utilized as a functional food ingredient (Ma et al. 1996). The outer covering of soybean removed during initial processing is referred to as soy bran. Psodorov et al. (2015) reported that soy bran particles (<50 μm) possess ideal textural and sensorial characteristics to be used as a fat replacer in the development of gluten-free cookies and cakes.

1.5.4.7 Green Vegetable Soybean (Edamame)

Edamame, a specialty soybean, is harvested when the beans are still immature, green, and sweet-tasting and have expanded 80–90% of the pod and is served as a snack or a main vegetable dish in East Asia (Konovsky et al. 1994).

1.5.5 Soy-Based Infant Formulas

Soy-based infant formulas constitute a soy protein isolate powder as the milk substitute and are aimed for the infants suffering with galactosemia and lactase deficiency. The soy-based infant formulas are quite popular and constitute nearly 25% of the formula market in the United States (Bhatia and Greer 2008).

1.5.6 Hydrolyzed Vegetable Protein (HVP)

HVP, a flavor protein produced by the hydrolysis of untoasted defatted soybean flour, is commonly used as a flavor enhancer in numerous food applications such as in soups, broths, sauces, gravies, etc. The typical taste (umami or the fifth taste) of HVP is contributed mostly by the presence of free amino acids (glutamic acid), smaller peptides, salts, and various other volatile compounds (Aaslyng et al. 1998).

1.5.7 Lecithin

Soybean lecithin, a by-product of soybean processing, is an important emulsifier used in the food, pharmaceutical, feed, and technical industries. It contains 37% neutral oils, 18% phosphatidylcholine (PC), 14% phosphatidylethanolamine (PE), 11% glycolipids, 9% phosphatidylinositol (PI), 5% phosphatidic acid (PA), 5% complex sugars, and 2% phospholipids (PL) (Wu and Wang 2003).

1.6 Alternative Applications

1.6.1 Animal Feed

Soybean meal is a major protein, mineral, and vitamin source in animal feed, and around 90–95% of the total soybean meal produced is utilized for livestock feed. Soy hulls, a by-product resulting from the processing of soybean, are also used widely as animal feed (Horan 1974; Peisker 2001).

1.6.2 Soybean Protein Fiber (SPF)

Soybean protein fiber (SPF) is the protein fiber produced from soybean cake and is quite similar to synthetic fiber. It is used as a blend with cashmere to give smoothness, with wool to reduce the shrinkage, and with silk to prevent stickiness when wet. Apart from these it also provides strength, comfort, easy to care properties, absorbency, and luster (Rijavec and Zupin 2011).

1.6.3 Soy Oil

Soybean oil finds numerous applications in the production of drying oil, inks for newspaper and offset printing, plasticizer, surfactant, dimmer acids, hydraulic fluids, insecticides and fungicides, solvents and cleaners, water-dispersible poly resins, and biodiesel (Honary 1996; Sonntag 1985; Kinney and Clemente 2005).

1.6.4 Soy Protein

Soy protein concentrate is used as a nutrient base for fermentation in the production of pharmaceuticals, gums, and gels. It is also utilized in the production of plastics, cosmetics, and wood replacers (Kato 2002; Huang and Sun 2000; Wang et al. 2007).

1.6.5 Soy Lecithin

Soy lecithin is used in the automotive industry for cleaning as well as a chelating agent. In the cosmetic and pharmaceutical industry, it finds its use in controlling and modification of fat crystal structure. It is used as an emollient in the shampoo products, as a lubricator in the shock absorbers and hydraulics, as a wetting agent, and softening and curing agent in leather tanning agent (Szuhaj 1983; Ghosh and Bhattacharyya 1997; Xu et al. 2011; Cerminati et al. 2019).

1.7 Conclusion

Soybean is a rich source of lipids and proteins and contains numerous phytonutrients such as saponins, bioactive peptides, phytosterols, and phenolic compounds; thus conferring a plethora of health benefits like hypoglycemic, hypolipidemic, antiobesity, hepatoprotective, anticancer, etc. The processing conditions like soaking, roasting, germination, autoclaving, etc. alleviate antinutrients like oxalates, phytic acids, saponins, etc. and, thus, enhance functionality of soybean in food industry. Numerous products like soybean oil, soy protein isolates, soy protein concentrates, soy textured protein, soy flour/grits, and traditional products like soy milk, tofu, natto, miso, etc. are prepared from soybeans which are not only nutritionally superior but also possess therapeutic properties. However, long-term human studies are required to further claim the health benefits of soybean, soy bioactive agents, and soy products and to elucidate their mechanism as therapeutic agents.

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