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Volume III

D. K. Salunkhe
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PREFACE

The population explosion has created food shortages in several countries in Asia, Africa, and Latin America. The problem of unavailability of sufficient quantity and quality food has been further compounded due to natural calamities like flood, cyclone, and famine. The world population in 2000 A.D. is estimated to be more than 6 billion. The increases in population are expected to occur mostly in developing countries where resources for producing more food to match the demand of the growing population are limited. The scientific advancements in crop production have increased the yields of principal food crops. However, the impact of such increases is not apparent due to the increase in population in these countries. In recent years, there has been a rapid rise in prices of agricultural inputs such as fertilizers, insecticides, and pesticides. This has restricted producers to intensive farming in areas where the density of population is high and a major proportion of the population subsists below the poverty level.

There is a chronic protein deficiency in almost every developing country. A massive increase in vegetable protein supply in malnourished areas would present less difficult, less expensive, and more energy prospects than boosting the supply of animal proteins. Food legumes are leading candidates since they contain more protein than almost any plant products. The "Green Revolution" in developing countries has not increased the yield of food legumes. On the contrary, emphasis on cereals has often led to decreased legume production. Only a similar revolution in production of legumes can eliminate protein malnutrition in the immediate future. As the cost of animal protein sources such as meat, milk, eggs, and fish slowly increases, legume offers a way to bridge the problem of an enlarging protein gap in developing countries.

Food legumes form important sources in developing countries. These are used mostly as animal feed in developed countries. The "Green Revolution" in developing countries has a negative impact on the production of food legumes. With the exception of soybeans, there was a decline in production of most food legumes in the year 1983 as compared to the world production figures of 1973. This is due mainly to a decrease in area under these crops. The production of legumes is restricted mainly to developing countries where they are used as human food. These are the countries where the yields per hectare of legume crops are lowest. The availability of food legumes in these countries ranges from 14 to 54 g/d.

In addition to the seeds, legumes offer a variety of other edible products. Many immature pods are edible at 2 or 3 weeks before the fibers lignify and harden. At this stage, they are green and succulent and can be used as green vegetables. Although they have less production than mature seeds, they are rich in vitamins and soluble carbohydrates. The mature seeds are good sources of fiber, proteins, minerals, and vitamins. The relative proportion of essential amino acids is not as well balanced for human dietary requirements as it is in meat, milk, or fish. Most legume proteins are deficient in methionine. However, these proteins usually contain more than adequate levels of some of the nutritionally important amino acids (such as lysine) which is deficient in most cereals. The combination of cereals and legumes provide a good balance of amino acids since cereals supply adequate methionine.

Food legumes are known to contain several antinutritional factors such as trypsin inhibitors, chymotrypsin inhibitors, lectins, phytates, polyphenols, flatulence factors, and other antinutritional factors such as lathyrogen, goitrogen, etc. depending upon the type of legume. The available evidence suggests that most of these antinutrients can be eliminated or reduced significantly by processing. To eliminate toxins a widespread practice in the Orient is to treat legume seeds by fermentation, or by sprouting and cooking before consumption. These processes produce wholesome, edible products essentially free of toxic material. Some compounds in legume seeds interfere with digestion without being truly toxic. Such substances occur in many legumes. If they are not inactivated, they may inhibit enzymes that digest proteins or they may impede the absorption of amino acids from the digestive tract;

both processes cause protein to be wasted. Some legumes also contain certain compounds that cause flatulence and other (lectins) that agglutinate certain blood cells. Phytates and polyphenols are known to decrease the availability of proteins, vitamins, and minerals.

Food legumes are processed in a variety of ways. The common methods are canning, milling, cooking, germination, fermentation, roasting, puffing, and preparation of protein concentrates and isolates. It has been shown that processing helps to eliminate or reduce the level of toxic factors and improve the nutritional quality of food legumes. However, significant amounts of minerals and vitamins are lost during processing. Excessive heat processing affects amino acids and proteins resulting in nutritional quality loss. Hence, it is necessary to make certain that processing conditions reach and do not exceed the optimum level to eliminate the effects of various antinutrients. When proteins are extracted from food legumes, alkali and acid treatments are commonly employed. These treatments results in modification of amino acids and proteins which exerts adverse effects of nutritive value of proteins. Such processes requires careful manipulation to avoid possible losses in nutritional quality of food legumes.

The seeds of legumes are stored under improper storage conditions which result in the hard-to-cook phenomenon. Significant losses in quantity and quality occur due to insects, rodents, and microorganisms during storage. The control of these losses by employing improved storage technology can improve the supply of food legumes in many developing countries. Food legumes are utilized in the human diet in numerous ways. In developed countries, these are available as dry seeds, fried seeds, seeds canned in brine, or canned in brine with meat, and in mixed vegetables. In developing countries, several fermented and deep-fat-fried products are prepared from legumes. In these countries, food legume preparations are consumed in conjunction with certain cereals and/or dairy products. During processing, several desirable and certain undesirable changes occur in the food. In order to improve the utilization of food legumes in human nutrition, optimum processing conditions need to be worked out for various legume-based products.

In the recent past, numerous scientific reports have been published on nutritional composition, processing, and utilization of food legumes. Among the legumes, soybeans, peanuts, *Phaseolus* beans, and faba beans are most extensively studied. However, information on the above aspects of other legumes is very limited. This book is an attempt to compile our own research and tabulate data available on above aspects of commonly consumed food legumes in the world. We hope it will serve as a reference book for students, researchers, and professionals involved in nutrition, food science, and other related areas of science.

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THE EDITORS

D. K. Salunkhe is a Professor of Nutrition and Food Sciences at Utah State University, Logan, Utah. Under his guidance, 80 postgraduate students received their M.Sc. or Ph.D. degrees. He has authored about 400 scientific papers, book chapters and reviews. Some of his articles received recognition and awards as outstanding articles in biological journals.

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Professor Salunkhe was Sigma Xi President, Utah State University Chapter; Fellow of Utah Academy of Sciences, Arts and Letters; Fellow of the Institute of Food Technologists; and Danforth Foundation Faculty Associate. He delivered the Utah State University 50th Faculty Honor Lecture ''Food, Nutrition, and Health: Problems and Prospects'', on the basis of his creative activities in research and graduate teaching.

Professor Salunkhe was Vice-Chancellor of Marathwada Agricultural University, Parbhani, and Mahatma Phule Agricultural University, Rahuri, in India during 1975 to 1976 and 1980 to 1986, respectively.

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SOYBEAN

M. P. Vaidehi and S. S. Kadam

INTRODUCTION

Soybean (*Glycine max* [L.] Merr.), an important legume belonging to the family Leguminosae, subfamily Papilionoideae, is grown as a food crop.[1] There are three species of soybean. They are *Glycine ussuriensis* (wild), *G. max* (cultivated), and *G. gracilis* (intermediate). *G. max* is commonly grown throughout the world. There are hundreds of cultivars available that have been adapted to various regions. In addition to these field varieties, there are a number of garden-type soybean cultivars that are believed to have better flavor and texture. The U.S. produces nearly 70% of the total world production of soybeans.[2] South America, Brazil, and Argentina produce substantial amounts of soybeans. Asian countries where the soybean is cultivated include China, Japan, Korea, Indonesia, Thailand, and the Philippines.

SEED STRUCTURE

The seeds of different varieties of soybean are generally similar in structure. However, they vary significantly in color. Soybean seeds have two major parts, the seed coat and the cotyledons. The hilum is distinct with a clear slit and the embryo shows the usual leguminous feature of two bulky cotyldeons. The bulk of the proteins in soybean seeds are stored in protein bodies[3] which may vary from 2 to 20 μm in diameter. Oil is located in smaller structures called spherosomes which are interspersed between the protein bodies and are 0.2 to 0.5 μm in diameter. Soybean seeds constitute about 8% hull, 90% cotyledon, and 2% hypocotyl and plumule.[4,5]

CHEMICAL COMPOSITION

Proximate Composition

The proximate compositions of three fractions of soybean seeds are presented in Table 1. Protein and oil make up about 60% of the bean, but about one third consists of carbohydrates, including polysaccharides, stachyose (3.8%) raffinose (1.1%), and sucrose (5.0%).[6] Phosphatides, sterols, ash, and other constituents are also present as minor constituents. A variation ranging from 13.9 to 23.2% in oil and from 32.4 to 50.2% in protein is also documented.[7-9] This variation in protein and oil content in soybeans is due to the locality where the beans are grown and the cultivar of the bean.[6] Krober and Cartter[10] found that oil, sugars, and other nonprotein components are affected most by changes in protein content. When protein content is increased, there is a significant decrease in nonprotein constituents such as oil, sugar, and pentosans.[10,11] Soybeans contain small quantities of peptides and amino acids having variable molecular dimensions which may occur as the residue of incomplete protein synthesis or possibly as the result of protein degradation.[12] A significant variation in nonprotein nitrogen in soybean meal has been reported.[13,14] The lipid content of soybeans and the composition of their fatty acid is influenced by genetic as well as environmental factors.[15-19] A variation in mineral content in ten varieties of soybean grown at five locations for 5 years reported by Cartter and Hopper[6] is presented in Table 2. These results indicate that the proximate composition of the seed is influenced by genetic as well as environmental factors.

Table 1
AVERAGE COMPOSITION (%) OF SOYBEAN SEED PARTS[6]

Constituent	Whole seed	Cotyledons	Hypocotyl	Hull
U.S. Soybeans: Average of Six Cultivars				
Crude protein	40.4	43.4	40.8	9.0
Crude fat	22.3	24.3	12.0	0.9
N-free extract + fiber	31.9	27.4	42.7	86.2
Ash	4.9	5.0	4.5	4.0
Japanese Soybeans: Average of Three Cultivars				
Crude protein	39.2	41.7	40.7	8.6
Crude fat	18.4	20.0	11.2	1.3
N-free extract + fiber	37.4	33.3	44.0	85.6
Ash	5.0	5.0	4.2	4.5

Table 2
AVERAGE ASH, PHOSPHORUS, POTASSIUM, AND CALCIUM (%) FOR TEN CULTIVARS OF SOYBEANS GROWN AT FIVE LOCATIONS FOR 5 YEARS[6]

Strain	Ash	Phosphorus	Potassium	Calcium
Mandarin	5.37	0.695	1.64	0.386
Mukden	5.00	0.660	1.74	0.240
Dunfield A	4.65	0.626	1.62	0.226
Dunfield B	4.61	0.627	1.58	0.221
Illini	4.81	0.623	1.67	0.252
Manchu	5.12	0.670	1.67	0.313
Scioto	5.17	0.658	1.68	0.343
T 117	5.02	0.654	1.67	0.248
Peking	5.21	0.727	1.75	0.272
Boone	4.97	0.653	1.71	0.253
Average	4.99	0.659	1.67	0.275

Carbohydrates

Carbohydrates constitute a major portion of food legumes. These include starch, sugars, crude fiber, and other minor carbohydrates such as pectic substances, arabinogalactans, and oxyloglucans.[20-23] Soybean seeds lack starch. Hence, most of the studies on soybean carbohydrates are restricted mostly to sugars. The principal sugars of soybeans are sucrose, raffinose, stachyose, and verbascose (Table 3).

Proteins

Content

Soybeans are an excellent source of proteins. A significant variation in protein content exists from cultivar to cultivar in soybeans. The protein content ranges from 35 to 44%. However, some strains have as high as 50% protein.[9,24] There is a negative correlation between protein content and yield.[24,25] There is also an inverse relationship between protein and oil contents so that strains having a higher protein content will have a lower oil content.[25]

Table 3
SUGARS (%) IN SEED PARTS OF SOYBEANS

Sugar	Whole seeds	Defatted cotyledons	Defatted hypocotyl	Hull
Sucrose	4.1	6.2	6.0	0.58
Raffinose	1.1	1.4	1.7	0.11
Stachyose	3.7	5.2	8.4	0.39
Arabinose	0.002	—	—	0.023
Glucose	0.005	—	—	0.06

From Kawamura, S., *Kagawa Univ. Fac. Tech. Bull.*, 15, 117, 1967. With permission.

Table 4
COMPONENTS OF ULTRACENTRIFUGE FRACTIONS OF WATER EXTRACTABLE SOYBEAN PROTEINS[35]

Fraction	% of total	Components	Mol. wt.
2S	22	Trypsin inhibitors	8,000—21,000
		Cytochrome C	12,500
		Chalcone-flavone isomerase	15,600
		Alcohol dehydrogenase	53,000
		β-Amylase	57,000
7S	37	Malate dehydrogenase	67,000—70,000
		Lipoxygenase	100,000
		7S Globulin (γ-conglycinin)	104,000
		Agglutinins	110,000
		Lactate dehydrogenase	140,000
		Malate dehydrogenase	140,000—145,000
		α-D-galactosidase	150,000
		α-D-mannosidase	170,000—180,000
		7S Globulins	180,000
		Acid phosphatase	240,000
11S	31	11S Globulin (glycinin)	307,000—317,000
15S + >15S	11	Urease	480,000

Properties

Most of the proteins in soybeans are high in molecular weight; about 80% of the proteins have molecular weights of 100,000 or higher. Based on the sedimentation coefficient, water-soluble proteins of soybeans are resolved into four fractions, with approximate sedimentation coefficients of 2S, 11S, and 15S. These fractions are not homogeneous. The protein components that have been isolated and characterized have molecular weights ranging from 8000 to 480,000 and many of them are enzymes that occur in small amounts (Table 4). Two proteins, 7S and 11S globulins, constitute the major proteins in soybean. The 7S globulins constitute about 60% of the total 7S fraction or 22% of the total protein; the 11S fraction consists of a single protein, the 11S globulin, although there is evidence for genetic polymorphism of this protein.[26] The 7S and 11S globulins thus make up 50% of the total proteins in soybeans. The 11S and 15S protein fractions precipitate quantitatively when a water extract of defatted soybean flakes is adjusted to pH 4.6, whereas 2S and 7S fractions precipitate only partially. Consequently, soybean protein isolates contain all four ultracentrifugal fractions, but with reduced amounts of the 2S and 7S fractions as compared to the

Table 5
FUNCTIONAL PROPERTIES OF SOYBEAN PROTEINS IN FOOD SYSTEM[35]

Functional property	Source of protein[a]	Food system
Adhesion	C, I	Sausages, luncheon meats, meat patties, meat loaves and rolls
	I	Dehydrated meats
Aeration	I	Whipped toppings
		Chiffon mixes
		Confections
Color control		
Bleaching	F	Breads
Browning	F	Breads
Dough formation	F, C, I	Baked goods
Emulsification		
Emulsifying capacity	F, C, I	Frankfurters, bologna, sausages
		Bread, cakes, soups
Emulsion stability	F, C, I	Frankfurters, bologna, sausages
Fat absorption		
Promotion	F, C, I	Frankfurters, bologna, sausages, meat patties
Prevention	F	Doughnuts
		Pie crusts
Solubility-dispersibility texture		
Viscosity	F	Soups
Film formation	I	Frankfurters, bologna
	I	Yuba
Gelation	F, C, I	Fish paste
	Soy milk	Tofu
	I	Cured meats
Chip and chunk formation	F, C	Extruded meat extenders and analogs
Fiber formation	I	Meat extenders and analogs
Water binding	I	Minced fish
	I	Turkey rolls
	I	Minced meat

[a] F, C, I denotes flours, concentrates, and isolates, respectively.

starting water extract.[26-28] The 7S and 11S globulins have been purified and characterized.[29-32] Both globulins are sensitive to changes in their ionic environment in aqueous systems. When ionic strength is changed, the proteins undergo association-dissociation reactions.

Soybean proteins are often added to food at low levels to utilize their functional properties, such as emulsification, water absorption, and adhesion that impart desirable characteristics to food.[35,39-41] At these levels, the contribution to nutrition is minor. At a higher level, proteins may be significant sources of protein as well as contributing functional effects. The functional properties that have been ascribed to soybean proteins are summarized in Table 5.

Amino Acid Composition

The amino acid composition of soybean meal is presented in Table 6. The high lysine

Table 6
AMINO ACID CONTENT OF SOYBEAN FLOUR

Amino acid	Content (g/16 g N)
Lysine	6.4
Methionine	1.1
Cystine	1.4
Tryptophan	1.4
Threonine	3.9
Isoleucine	4.6
Leucine	7.8
Phenylalanine	5.0
Valine	4.6
Arginine	7.3
Histidine	2.6
Tyrosine	3.8
Serine	5.5
Glutamic acid	11.8
Glycine	4.3
Alanine	4.3
Proline	5.5
Ammonia	1.9

content of soy proteins makes them useful for supplementing cereal proteins which are low in lysine. Methionine is the first limiting amino acid of soy proteins and this deficiency needs to be considered when proteins are used for nutritional purposes. Cystine content is also low when compared to egg or cereal proteins.

Modification of Proteins

Fujimaki et al.[36] studied the plastein reaction of soy proteins when protein is hydrolyzed enzymatically and the hydrolysate is incubated with certain proteolytic enzymes with appropriate conditions. The hydrolysis is reversed and a high molecular weight protein-like substance is formed having somewhat different properties from the original protein. The new protein-like substance is called "plastein" (see Volume I, Proteins). When soy proteins are partially hydrolyzed with pepsin, the hydrolysate is bitter because of the presence of bitter peptides; on treatment of the hydrolysate with α-chymotrypsin under suitable conditions, a plastein is formed and the bitterness gradually disappears. Yamashita et al.[37] prepared a soybean plastein having an amino acid composition similar to that of the original protein.

Protein Quality

Comparing soy proteins with the FAO/WHO amino acid pattern,[42] it is evident that soy protein scores range from 71 (flour) to 86 (concentrate) based on sulfur amino acids which are first limiting (Table 7). However, when the FNB reference pattern with its lower sulfur amino acid requirement is used, soy proteins score 96 to 100. By contrast, the rat amino acid pattern has a high requirement of methionine plus cystine and results in soy protein scores of only 50 to 60. The protein efficiency ratio (PER) values of various soybean products are presented in Tables 8 and 9. None of the soy products has a PER value equal to that of casein because of the low methionine content relative to the requirements of rats. Since the amino acid requirements of man and rat differ, the use of the PER to evaluate protein quality for humans has been questioned.[45,46] Recent studies have shown that soy proteins are of higher nutritional value for humans than is indicated by the rat assay.[49-51] Data presented in Table 10 indicate that supplementation of soy protein does not offer additional nutritional advantages except perhaps for infants when soybeans are the sole source of protein.

Table 7
COMPARISON OF ESSENTIAL AMINO ACID REQUIREMENT FOR MAN AND THE RAT WITH COMPOSITION OF SOYBEAN PROTEINS[a42-44]

Amino acid	Requirements (%)			Content in soy products (%)		
	Man		Rat			
	FAO/WHO[b]	FNB[c]	(NRC/NAS[d])	Flour	Concentrate	Isolate
Lysine	5.5	5.1	5.8	6.4	6.3	6.4
Threonine	4.0	3.5	4.2	3.9	4.2	3.7
Methionine + cystine	3.5	2.6	5.0	2.5	3.0	2.6
Tryptophan	1.0	1.1	1.3	1.4	1.5	1.4
Valine	5.0	4.8	5.0	4.6	4.9	4.7
Leucine	7.0	7.0	6.3	7.8	7.8	8.0
Isoleucine	4.0	4.2	4.2	4.6	4.8	4.9
Phenylalanine + tyrosine	6.0	7.3	6.7	8.8	9.1	9.3
Histidine	—	1.7	2.5	2.6	2.7	2.7
Arginine	—	—	5.0	7.3	7.5	7.8

[a] Expressed as percent of protein.
[b] Food and Agriculture Organization/World Health Organization.[42]
[c] Reference 43.
[d] National Research Council/National Academy of Sciences.[44]

Table 8
PROTEIN QUALITY OF SOYBEAN PRODUCTS[47,48]

Product	PER
Flour	
Raw	1.3
Lightly toasted	1.6
Fully toasted	2.2
Concentrate	2.3
Isolate	1.1—1.2
Casein (reference)	2.5

Note: PER, protein efficiency ratio.

Lipids

Content and Composition

Soybeans are primarily utilized in the U.S. as a source of oil.[52] Soybean oil dominates the supply of vegetable oils consumed in the U.S. and other parts of the world and most of the oil is used in the preparation of food products. Soybean lipids are deposited in spherosomes which have been identified by electron microscopy.[53] Spherosomes in soybean cotyledons are interspersed between protein bodies and are about 0.2 to 0.5 μm in diameter. The total lipid content in soybean ranges from 18 to 23%. Soybean seeds contain 88.10% neutral lipids, 9.8% phospholipids, and 1.6% glycolipids.[52] Neutral lipids primarily consist of triglycerides, accompanied by smaller proportions of free fatty acids, sterols, and sterol esters. The main components in neutral lipids, phospholipids, and glycolipids are palmitic, oleic, linoleic, and linolenic acids.[54]