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HANDBOOK *of* WORLD FOOD LEGUMES: Nutritional Chemistry, Processing Technology, and Utilization

Volume I

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S. S. Kadam

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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.

D. K. Salunkhe
S. S. Kadam

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.

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SERIES TABLE OF CONTENTS

TABLE OF CONTENTS

Volume I

INTRODUCTION

D. K. Salunkhe and S. S. Kadam

The world food production is lagging behind the population despite all efforts to reverse this trend. The present population of this planet may be more than 6 billion by the year 2000, if the present growth rates remain unchecked. It is estimated that in less than 15 years, the population of Asia may exceed 2500 million or more than half the entire population of the earth. Many developing nations are losing the capacity to feed themselves. As these nations contain much of the present and will have even more of the future population of the world, supplying sufficient food for them would become one of the most important problems for the balance of the 20th century.

While the quantity of food (calories) is already causing considerable concern in many areas throughout the developing world, the quality (notably protein) of the food consumption pattern is even more critical. For over one third of the present population in developing countries, the protein-calories balance of the diet is inadequate.[2] Providing food to meet the calorie needs is not sufficient. Within this general food problem, the need to increase and improve the production and human use of protein in the developing countries is crucial. Growing nutritional deficiencies have even greater impact on young children in developing countries. In some countries, many survivors' physical growth and development are impaired. Thus, the nutritional deficiencies existing at the present time in many developing countries are already jeopardizing the future of many million people in the world.[3] It is recognized that the protein problem is reaching a critical stage. It is essential to close the present gap between world protein needs, protein supplies, and distribution to prevent an even more widespread protein deficiency in future generations.

The success of agriculture since World War II has depended upon the availability of cheap, abundant energy that facilitated the use of fertilizers, pesticides, irrigation, and mechanization. Now energy is no longer cheap nor abundant and neither is fertilizer, especially nitrogenous fertilizers. Under pressure of population and shortages of energy and fertilizer, techniques that can increase food production without expending large quantities of energy are assuming great importance. The most important task facing mankind today is to solve the problems of world hunger and malnutrition by methods that lessen exploitation of nonrenewable energy resources. The huge increase in fertilizer nitrogen cost in developing countries has perhaps been the most insidious effect of the recent energy crisis. Under these conditions, food legumes and biological nitrogen fixation associated with these crops take on new importance.

The word "legume" is derived from the Latin "legumen" which means seeds harvested in pods. An alternative term for edible seeds of leguminous plants is "pulse" from Latin "puls", meaning pottage. The current literature sometimes refers to leguminous seeds as grain legumes.[4] The term food legumes is used to cover both the immature pods and seeds as well as mature dry seeds used for human foods. In accordance with present Food and Agriculture Organization (FAO) practice, the word legume is used for all leguminous plants. For those containing only small amounts of fat, such as French beans, lima beans, etc., the term "pulse" is used and for those containing a high proportion of fat, such as soybeans and peanuts, the term "leguminous oilseed" is used. Among the various legumes cultivated, about 20 are most commonly grown in different continents of the world and are used for human consumption (Table 1). Of the various food legumes cultivated, soybeans, peanuts, dry beans, peas, broad beans, chickpeas, and lentils are the major food legumes grown in all continents of the world. Other legumes are grown only in some countries, depending on the climatic conditions needed to support the growth and food habits of the consumers.

Table 1
MOST COMMON FOOD LEGUMES GROWN IN THE WORLD

Scientific name	Common name
Arachis hypogaea L.	Groundnut, peanut
Cajanus cajan (L.) Millsp.	Pigeonpea, red gram, Congo pea, Arhar, Tur, Gongo pea
Cicer arietinum L.	Chickpea, Bengal gram, garbanzo gram
Glycine max (L.) Merr.	Soybean, soya
Lablab purpureus (L.) Sweet	Hyacinth bean, Egyptian bean, Val.
Lathyrus sativus L.	Khesari, chickling vetch, grasspea
Lens culinaris Medik.	Lentil, Masur
Lupinus albus L.	White lupine
Lupinus angustifolius L.	Blue lupine, New Zealand blue lupine
Lupinus luteus L.	European yellow lupine
Macrotyloma uniflorum (Lam.) Verdc.	Horse gram, Madras gram, Kulthi
Phaseolus lunatus L.	Lima bean, butter bean
Phaseolus vulgaris L.	Bean, common bean, French bean, field bean, haricot bean, pinto bean, navy bean, dry bean
Pisum sativum L.	Common or garden pea, dry pea
Psophocarpus tetragonolobus (L.) DC.	Winged bean, Goa bean, four-angled bean, Manila bean, princess pea
Vicia faba L.	Broad bean, faba bean, horse bean
Vigna aconitifolia (Jacq.) Marechal	Moth bean, mat bean
Vigna mungo (L.) Hopper	Urd, black gram
Vigna radiata (L.) Wilczek	Green gram, golden gram, mung bean
Vigna umbellata (Thumb.) Ohwi and Ohashi.	Rice bean, mambi bean
Vigna unguicula (L.) Walp. ssp. *unguiculata*	Cowpea, black-eyed pea, crowder pea
Voandzeia subterranea (L.) Thouars	Bambarra groundnut

Food legumes offer a relatively inexpensive source of protein which is valuable for developing countries. The seeds of these plants are the part most commonly eaten and most of them can be economically stored well for future use. The food value of legume seeds is high; they have about the same calorie value per unit weight as cereals and are fair sources of some vitamins and minerals. Their protein contents are generally about double that of most cereals. However, the protein quality is not as good as that of meat and other animal products. Beans are often thought of as "poor man's meat" and many of the world's poor could use more of them. Consumption is highest in India where both low purchasing power and religious restrictions on meat contribute to their greatest use. Consumption is also high in Latin America where beans are frequently served with all meals. They contain about 20 to 25% protein and about 2.5% fat (except soybeans, groundnuts, and winged beans). Legume proteins considered in isolation have a somewhat lower value than most other classes of protein, but they contribute substantially in fulfilling the protein requirements when combined with other proteins in a mixed diet.

Food legumes are considerably richer in calcium than most cereals and contain about 100 to 200 mg of calcium per 100 g. They are also considerably rich in iron, thiamin, riboflavin, and nicotinic acid as compared to cereals. Less well known is the fact that the ripe pods of several of the beans have a high sugar content and are consumed by man or livestock. Young sprouts or seedlings of various kinds of beans are popular foods in some places, particularly in Far Eastern countries.

A wider variety of beans can complement existing foods by providing additional proteins and vitamins. Food legumes are especially important as a complement to carbohydrate staples, such as rice, corn, and other cereals; cassava; and other root and tuber crops. In legume proteins, the relative proportions of the essential amino acids are not as well balanced for human dietary requirements as in meat, milk, or fish. Nonetheless, legume protein usually contains more than adequate levels of some of the nutritionally important amino acids, such as lysine, that are deficient in most cereals and other edible plant foods. The combination of cereals and beans provides a good balance of amino acids since cereals usually supply adequate methionine. Food legumes are good sources of dietary fiber. The crude fiber, protein, and lipid components of food legumes have been shown to have a hypocholesterolemic effect. This has generated interest in food legumes as human food in developed countries.

Food legumes are known to contain several antinutritional factors, such as trypsin and chymotrypsin inhibitors, phytates, lectins, polyphenols, flatulence factors, cyanogenic compounds, lathyrogens, estrogens, goiterogens, saponins, antivitamins, and allergens.[5] Some raw beans have been shown to be toxic to experimental animals.[6] The protease inhibitors, lectins, and other antinutrients are implicated in the toxicity of raw beans. Heat treatment has been well established to destroy proteinaceous antinutrients, such as protease inhibitors and lectins, but this treatment may destroy some of the amino acids and vitamins. For maintaining the nutritional value of food subjected to heat treatment, it is necessary to make certain that the heating temperature and length of processing reach, but do not exceed, the optimum temperature required to eliminate the effect of inhibitors without altering basic nutrients. Proteins in legumes are known to interact with lipids, tannins, phytates, flavor compounds, and pigments.[7] These interactions occur when legumes are processed and converted into products. This decreases the bioavailability of proteins. Similarly, tannins and phytates interact with minerals and vitamins, resulting in a decrease in bioavailability of minerals and vitamins.[8] Thus, bioavailability of nutrients depends not only on content of the nutrients in the seed, but also on the interaction of nutrients under various processing conditions.

In developing countries, legumes are processed using traditional methods. These include milling, soaking, germination, fermentation, and cooking.[2] Such processing has several nutritional advantages. These processes produce wholesome edible products having a reduced level of toxic compounds. The degree of elimination of toxic constituents depends on the type of legume and processing conditions. Recently, technology has been developed for extraction of proteins from food legumes. During extraction, physical and chemical changes occur which modify the nutritive value of protein or induce certain undesirable changes in protein.

Legumes are stored until the next harvest. Several chemical and biochemical changes occur in the seeds. One important change observed in stored seed is the change in the cooking behavior of seeds which leads to the ''hard-to-cook'' phenomenon.[2] It is established that prolonged cooking results in a decrease in protein digestibility. Hence, storage of seeds under optimum conditions is important.

The legumes are utilized in a variety of ways. Green seeds of peas, pigeonpeas, and lima beans are popular in different continents of the world. Chickpeas and pigeonpeas are mostly consumed in the form of *dhal*. Legumes like lentils, *Lathyrus* beans, and green gram are consumed as dried mature seeds after cooking. In developing countries, soybeans and broad beans are utilized for the preparation of protein concentrates and isolates which are used for enrichment of various food products. Various products such as milk, curd, and fermented products like *tempeh* and *idli* are prepared from legumes and are becoming popular all over the world. Many deep-fried products and weaning foods are prepared by using legume flours. This indicates various modes of utilization of legumes as human food. However, appropriate conditions of processing need to be developed for improving the nutritional functionality of these food products.

Economic circumstances are changing. It seems probable that the days of ''cheap'' food policies are numbered. The energy crisis is already at hand and a possible protein famine lies not too far in the distant future. The coming shortage of animal protein provides the legume with this opportunity. The efforts of all concerned with legume production will be concerned with an amino acid profile as close as possible to that of good animal protein. This may be produced by processing and blending protein from different sources, supplemented perhaps by addition of synthetic limiting essential amino acids. As the demand for such materials arises out of necessity, the economic picture will improve. In order to maintain this number, man will have to shorten food chains and subsist directly on plant proteins to a much greater extent. Food legumes undoubtedly have a greater role to play in the nutrition of the population in developing countries, the scope of which is only now beginning to be appreciated, and may be an important component in all-embracing efforts to avoid global starvation.

In the recent past, attempts have been made to compile information on nutritional composition, processing, and utilization of legumes in an FAO publication.[4] Recently, efforts have been made to minimize or eliminate postharvest food grain losses through improved postharvest technology. Information on loss reduction technology for food legumes has been recently reviewed.[2] All these attempts are directed toward improvement of the supply of food legumes in developing countries. However, progress can be made in the near future on the protein malnutrition problem only if basic food grains such as legumes are upgraded in nutritive quality,[9] by employing appropriate processing and storage conditions and utilizing legumes in different forms as a component of the human diet. It is expected that the information presented in this book will help to improve the contribution of food legumes in the human diet in developed as well as developing countries.

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PRODUCTION, DISTRIBUTION, AND CONSUMPTION

S. S. Kadam and D. K. Salunkhe

INTRODUCTION

Among several legumes cultivated, soybeans, groundnuts, dry beans, peas, broad beans, chickpeas, and lentils are the major food legumes grown in all continents of the world.[1] Other legumes are grown only in some countries, depending on the climatic conditions needed to support the growth and the food habits of the population. The production of major legumes in the world, developing and developed countries, is given in Table 1. In many agricultural systems throughout the world, legumes and cereals have traditionally been linked. They complement each other agriculturally, in terms of cropping pattern, and nutritionally, with legumes bringing necessary nutrients and variety to a diet based on cereals.[2] The production and yields of pulses, groundnuts, and soybeans for continents with data for cereals are presented in Table 2. Production of cereals in the last 10 years has increased far more than that of pulses. Groundnuts have shown a small increase, but the production of soybeans has more than doubled. The production figures for legumes in different continents for 1982 are given in Table 3. China and India are the major producers of food legumes (Table 4). These two countries contribute about 50% of the total production of legumes in the world. With the exception of soybeans and peas, the production of important food legumes is concentrated in developing countries.[3-5]

The production of cereals and pulses in selected countries is presented in Table 5. In India, Pakistan, and Mexico, where pulses have always played an important role in agricultural systems and human nutrition, the increase in cereal production with high-yielding varieties was not matched by an increase in pulse production. In Brazil, production of soybeans has increased ninefold in 10 years. The reasons for decline in production of pulses in developing countries are twofold.[2] In the first place, the traditional caution of farmers prevents them from allocating too high a proportion of their land to pulses, and in the second place, modern technologies in agriculture, in particular the green revolution, have had their effect. The farmers' caution with regard to pulses is caused mainly by low yields, uncertain harvests, slow maturation, and sensitivity of legumes to growing conditions at all periods of development and severe losses caused by pests.[2] In addition, methods of preparation and cooking necessary to ensure a digestible product are often lengthy and costly in terms of fuel consumption.

PRODUCTION AND DISTRIBUTION

A large number of legume species are cultivated. Because food legumes are grown in developing countries on a small scale in order to meet the domestic needs of the family, no accurate data are available on the production of food legumes in different regions or countries. Only that part of the produce calculated as surplus is sold in the market or in some cases, the family supply is sold when money is needed. Since all food legumes are not grown in all countries, the production figures are mainly available for those crops which are commonly grown in developed or developing countries.

Soybeans

The soybean, *Glycine max* (L.) Merr., is an important legume grown mainly as a food crop. Production figures based on Food and Agriculture Organization (FAO) estimates[4] are presented in Tables 6 and 7. The U.S. produces nearly 70% of the total world production

Table 1
PRODUCTION OF IMPORTANT FOOD LEGUMES IN THE WORLD[4]

Legume	Total production	Developed nations	Developing nations
Soybeans	92,982	64,401	28,581
Groundnuts	18,580	1,840	16,740
Dry beans	14,195	2,116	12,079
Peas	9,807	6,552	3,255
Chickpeas	6,158	346	5,812
Broad beans	4,224	464	5,759
Lentils	1,292	231	1,061

[a] Production in thousand metric tons.

Table 2
PRODUCTION AND YIELDS OF CEREALS, PULSES, GROUNDNUTS, AND SOYBEANS BY CONTINENTS[4]

Continent	Food group	Production (thousand metric tons)	Yield (kg/ha)
World	Total cereals	1,553,076	2,041
	Total pulses	51,873	715
	Groundnuts	19,228	1,016
	Soybeans	94,207	1,660
Africa	Total cereals	66,480	918
	Total pulses	5,103	433
	Groundnuts	5,522	891
	Soybeans	241	840
North and Central America	Total cereals	356,703	3,619
	Total pulses	3,004	922
	Groundnuts	1,985	2,634
	Soybeans	63,088	2,160
Asia	Total cereals	629,984	1,831
	Total pulses	31,057	710
	Groundnuts	10,407	932
	Soybeans	15,047	915
Europe	Total cereals	239,984	3,407
	Total pulses	2,545	851
	Groundnuts	27	1,828
	Soybeans	672	1,498
Oceania	Total cereals	24,312	1,476
	Total pulses	169	902
	Groundnuts	63	1,629
	Soybeans	103	1,947
U.S.S.R.	Total cereals	172,011	1,418
	Total pulses	6,800	1,352
	Groundnuts	1	1,200
	Soybeans	600	716

of soybeans. South America, Brazil, and Argentina produce a substantial amount of soybeans. Asian countries where the soybean is cultivated include China, Japan, Korea, India, Indonesia, Thailand, and the Philippines. The per hectare yield of soybeans is highest in the U.S. There are three species of soybeans. They are *Glycine ussuriensis* (wild). *G. max* (cultivated), and *G. gracilis* (intermediate). *G. max* L. is commonly grown throughout the world.