SOYBEAN CHEMISTRY AND TECHNOLOGY

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FOREWORD

IN THE long stream of agricultural history, few events are more fascinating than the astonishing rise of the soybean in America.

From a minor forage crop little over a decade ago, production has doubled and doubled time and again until, last year, it topped the huge total of 209 million bushels, a magnificent contribution to the war effort.

In production of edible oil, it is now a leader in the field, having surged ahead of the great cottonseed oil output.

Production of soybean oil meal, a superior protein ingredient for livestock and poultry feeds, has swollen to figures undreamed of a few years ago.

And now soy protein has pushed into the human food field, with production capacity estimated by the government at the end of 1943 as one and a half billion pounds. Soy flour, soy grits and soy flakes are moving in a steady stream to allied nations; they are going into the rations of our fighting men; they are included in bakery and innumerable other food products, and are being packaged for direct sales by stores to the housewives of the nation. As a meat supplement, soy protein is gaining ground.

Such is the record of the versatile oriental bean in a short span of time.

Much of the credit must go to the men of the laboratory,

who, staring into test tubes with repressed excitement, have made new discoveries, and new contributions, one after another, to the forward stride of the industry.

There has been a tremendous public demand for more scientific facts—for the chemistry and technology of the soybean and its products.

At last, the present work has been concluded and will be hailed everywhere for its clarity of approach and its thoroughness of execution. It was a monumental task, discharged as could be done only by scientists of broad perspective and infinite patience for detail.

The volume will be on the "must" list of all technical libraries here and abroad; professors, students, research workers, industrialists engaged in vegetable oil and protein trades, all will find it an indispensable mine of factual information. It is perhaps the most complete work of its kind on the ancient soybean, which pre-dates the Pyramids and was hoary with age before the building of the Tower of Babel, and centuries before Solomon fashioned his temple.

SOYBEAN NUTRITIONAL RESEARCH COUNCIL
EDWARD JEROME DIES, *President*

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INTRODUCTION

THE soybean, Soja max. (L.) Piper,[349] * also referred to by botanists as Soja hispida (Moench) and Glycine hispida (Moench) Maxim., is one of the oldest crops cultivated by man. Its early history is lost in antiquity. According to Morse and Cartter,[287] the plant was extensively cultivated in China long before written records were kept. According to these authors, the first record of the plant is contained in a materia medica written by Emperor Sheng Nung in 2838 B.C. Throughout the history of China and down to the present day, the soybean has been the most important cultivated legume, and probably the most important crop, to the existence of the Chinese people and to the Chinese civilization.

From China, the soybean has spread over a considerable portion of the world. The principal soybean producing countries are China, Manchuria, United States of America, Chosen, Japan, and Netherlands Indies in the order named. In the last few years, increasing quantities of soybeans have been grown in Europe, especially in Germany, the Balkan States, and the Union of Soviet Socialist Republics. England, South Africa, British East Africa, Algeria, Egypt, New South Wales, and New Zealand have experimented with soybeans, but commercial production has been negligible. The trend of soybean production, in various countries, is shown

* Small numbers refer to "Literature Cited," on pages 119 and 249.

in Table 1, which is reproduced from *Foreign Crops and Markets.*[440]

TABLE 1

Soybean Production in Specified Countries from 1935 to 1941

(Compiled from official sources and unofficial estimates.)

Country	1935 1,000 bushels	1936 1,000 bushels	1937 1,000 bushels	1938 1,000 bushels	1939 1,000 bushels	1940 1,000 bushels	1941 [a] 1,000 bushels
China [b]	184,415	215,728	213,189	207,600	203,900	216,800	[c]
Manchuria ..	141,793	152,375	159,907	157,445	144,952	140,617	[c]
United States	44,378	29,983	45,272	62,729	91,272	77,374	106,712
Chosen	20,738	17,937	20,205	18,333	[c]	[c]	[c]
Japan	10,719	12,485	13,473	[c]	[c]	[c]	[c]
Taiwan	139	162	158	146	[c]	[c]	[c]
Netherlands Indies	7,448	9,090	9,880	10,567	[c]	[c]	[c]
Rumania ...	424	1,367	2,584	1,803	3,532	3,600[d]	[c]
Bulgaria	[c]	179	419	246	613	1,415	[c]
Yugoslavia ..	36	22	54	140	103	294	[c]
Hungary	[c]	[c]	[c]	[c]	125	194	[c]
Total [e] ...	410,500	439,700	466,000	473,000	477,500	483,500	[c]

[a] Preliminary.

[b] Excluding Kwangsi Province, for 1935 to 1937, which normally produces about 2,500,000 bushels.

[c] Not available.

[d] Assuming that Bessarabia produces 80 per cent of the total.

[e] Includes a small amount for other minor-producing countries, but excludes the Soviet Union.

Although, China usually produces more soybeans than any other country and approximately as much as the two next largest producers, Manchuria and the United States, it is not a factor in world trade as practically the total production is domestically consumed. In addition to domestic produc-

tion, China normally takes important quantities of soybeans and soybean products from Manchuria. The latter country is the most important factor in the world soybean trade, although, in 1939, the United States exported 10.5 million bushels to European oil centers, principally the Netherlands and Scandinavian countries. Japan has been one of the largest importers of soybeans from Manchuria, but these imports have been decreasing. Germany's imports of soybeans have increased rapidly in recent years, reaching approximately 800,000 metric tons in 1938. Most of these imports came from Manchuria, but the United States, Rumania, and other Balkan States also contributed to the total. The world production for 1937 has been estimated at 12,454,000 metric tons or approximately 457,500,000 United States bushels. Data, covering imports and exports of soybeans and soybean oil, for all principal producing and consuming countries for the period of 1930 to 1937, are contained in the *Report of the Imperial Economic Committee* [193] to which the reader is referred for detailed information on this subject.

In the Orient, especially in China and Japan, soybeans are grown principally for the seed which has served for centuries as an important source of food. For this purpose, the beans are utilized in the preparation of numerous fresh, fermented, and dried products. Most familiar to Occidentals is the fermented product known as shoyu or soy sauce which is but one of the numerous derivatives of this versatile seed. Besides soy sauce, the beans are used in the form of flour, vegetable milk (fresh, condensed, and dried), curd or tofu, from which a variety of products is prepared, cheese, and the important fermented product known as miso. Large quantities of beans are also crushed for oil which is used for food and

numerous industrial purposes, and the resulting cake or meal is used chiefly as a fertilizer and as feed for animals. The roots are often dug and dried for fuel, especially in Manchuria, and the leaves, stalks, pods, and other refuse are used for feeding cattle. The use of soybean stalks, as a source of cellulose pulp,[49, 18] has been proposed, and a plant, capable of producing 15,000 tons of pulp annually, was erected at Kaiyan, Manchuria, in 1939. A Japanese patent,[283] covering the use of soybean refuse mixed with powdered coal and lime and pressed into briquets for fuel, has been granted.

In contrast to the food uses in the Orient, European countries have for many years imported considerable quantities of soybeans from Manchuria for the production of oil and meal. In the United States, the soybean has been used primarily for forage purposes, being either preserved extensively as hay or silage or cut and fed in the green state. It is also pastured extensively with hogs and sheep and used, to some extent, as a green manure or cover crop. More recently, soybeans have been grown extensively in the United States for the production of oil. During the last 15 years, both the total acreage, sown to soybeans, and the acreage, harvested for commercial beans, have greatly increased as is evident from Table 2.

"The marked increase in the production of soybeans in the Corn Belt has been conditioned by several factors. These include the ability of the soybean plant to withstand drought, its relative freedom from pest hazards, its adaptability to crop rotations, the possibility of harvesting the beans with a small combine, and the fact that soybeans provide an additional source of cash income for many farmers. The necessity for finding a more profitable crop than oats and, in some cases, corn has been important in bringing about increased soybean

production. In the South, where cotton acreage has been reduced considerably in recent years, soybeans, harvested mostly for hay, forage, and as a green-manure crop, also have been useful for replacement purposes." [444]

TABLE 2

ACREAGE, YIELD, AND PRODUCTION OF SOYBEANS IN THE UNITED STATES FROM 1924 TO 1943 *

Year	Acreage Grown Alone for All Purposes	Acreage Harvested for Beans	Average Yield Per Acre	Production
	1,000 Acres	1,000 Acres	Bushels	1,000 Bushels
1924	1,567	448	11.0	4,947
1925	1,539	415	11.7	4,875
1926	1,871	466	11.2	5,239
1927	2,057	568	12.2	6,938
1928	2,154	579	13.6	7,880
1929	2,400	708	13.3	9,398
1930	3,010	1,008	13.4	13,471
1931	3,738	1,104	15.2	16,733
1932	3,595	977	15.3	14,975
1933	3,365	997	13.2	13,147
1934	5,572	1,539	15.0	23,095
1935	6,640	2,697	16.5	44,378
1936	5,811	2,132	14.1	29,983
1937	6,171	2,549	17.8	45,272
1938	7,262	3,105	20.2	62,729
1939	9,506	4,417	20.7	91,272
1940	10,513	4,779	16.2	77,374
1941**	10,146	5,881	18.0	105,587
1942**	13,879	10,008	18.7	187,155
1943**, †	14,762	10,820	18.1	195,762

* U. S. Department of Agriculture, *Agricultural Statistics*, p. 196 (1942).

** Crop Reporting Board, Bureau of Agricultural Economics, U. S. Department of Agriculture, *Crop Report; Annual Summary* (1942 and 1943).

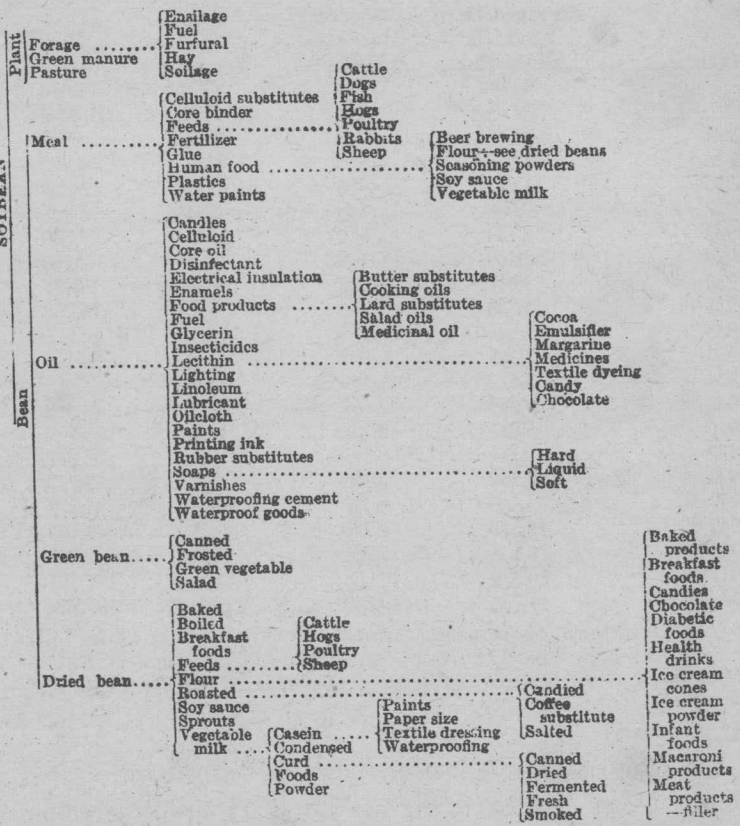
† Preliminary.

The marked increase in the production of soybeans, in the United States, has led, in the last few years, to the development of numerous food, feed, and industrial uses for both the meal and the oil. There are at present over 100 oil mills

processing soybeans * and several times that number of concerns are engaged in the manufacture of soybean flour and other food products and in the manufacture of various industrial products. Table 3, prepared by Mr. W. J. Morse of the United States Department of Agriculture, shows the diversity

TABLE 3

SOYBEAN UTILIZATION



* See list of oil mills in Part II.

of uses to which the different products of the soybean are put.

The soybean is an annual summer legume, requiring from 75 to 200 or more days to reach maturity. The plant, which grows to a height of from 2 to more than 6 feet, though more usually from 2 to 3½ feet, has rather woody and branched stems (Fig. 1).

The stems, leaves, and seed pods are covered with short reddish-brown or gray hairs. The flowers are small and inconspicuous, either white or purple and clustered in the axils of the leaves. The pods are from 1 to 2½ inches long and contain two to four seeds. When mature, the seeds may be yellow, green, brown, or black in color; and in shape, round, oval, or flattened like the lima bean.

The varieties of soybeans are very numerous and many hundreds of types and strains are known. They may be divided into three general groups with respect to their uses, namely, vegetable varieties, hay varieties, and grain or industrial varieties. The unusually large number of known varieties and strains of soybeans appears to be the result of the peculiar sensitivity of the plant to changes in soil and climate. The recognition of the sensitivity of the soybean to environment has been the basis of much of the breeding and adaptation studies which have been carried on in various countries of the world, particularly in the United States, Japan, Manchuria, China, India, Chosen, Germany, the Union of Soviet Socialist Republics, and other European countries. The chief objective of these studies has been to increase the yield of beans under local conditions; but, more recently, similar work has been conducted with a view of increasing the quality of beans, especially for industrial utilization.

The factors or characters which are included in the term

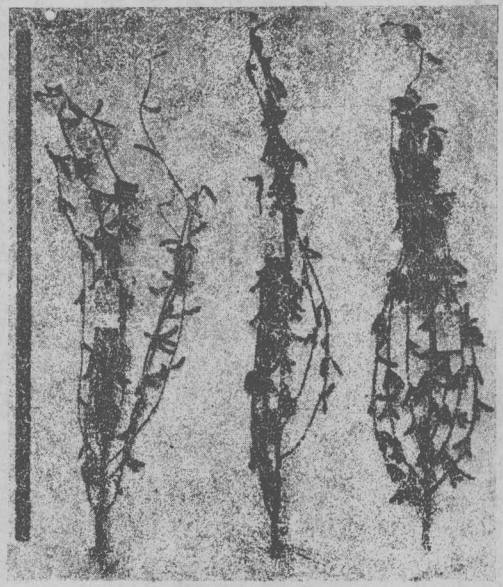


FIGURE 1

The Soybean Plant

In Foliage

Mature

quality, as applied to the industrial uses of soybeans, are principally oil content, iodine number of the oil, phosphatide content, and protein content. In response to the demand by oil mills for varieties of high oil content, breeding and selection from foreign introductions into the United States have led to the development of yellow-seeded varieties such as Illini, Dunfield, Mukden, Mandell, Scioto, Mansoy, Manchu, Mamredo, Delsta, Mandarin, Seneca, and many others which are particularly adapted to a given agricultural region.

The literature, pertaining to the effect of variety, climate, soil type, and maturity on the yield and quality of protein and oil, is very extensive and has been reported from every country in which the soybean has been grown. A similarly extensive literature, pertaining to the cultural practices, including harvesting and handling of the mature seed intended for commercial processing, is readily available.

Composition and Properties

From the chemical point of view, most seeds are extremely complex, containing, as they do, all the elements and compounds necessary to reproduce and nourish the new plant until it can form the necessary system of roots and leaves to obtain from the soil and atmosphere the materials essential for growth and maturation. The nature and chemical composition of some of the numerous products, stored by seeds, are known and their functions, in the reproduction of the plant, are understood. However, many substances, which are present in seeds, have not been completely characterized chemically and their probable functions provide food only for speculation.

To this general statement, the soybean is no exception and despite the considerable study, which has been devoted to the composition of the soybean seed, it may be said that only its grossest aspects are known and much is yet to be learned of the finer and less obvious details of its chemical structure. It is well known, for example, that the soybean seed consists principally of protein, oil, carbohydrates, and mineral constituents. It is also known that the protein is made up of a number of amino acids, that the oil contains a variety of mixed fatty acid glycerides and phosphatides, as well as unsaponifiable materials such as sterols, ketones, and hydrocarbons; that the carbohydrates are present in the form of sugars, cellulose, and various glycosides; and that the mineral constituents consist of potassium, calcium, phosphorus, and similar elements. Moreover, the soybean seed contains many minor constituents such as pigments, vitamins, enzymes, and antioxidant bodies, many of which have been isolated in pure form. Little is known regarding their structure, function, and use. Still other substances are undoubtedly present in the soybean seed, but only a guess may be hazarded as to their identity.

Not only are the chemical constituents of the soybean numerous and complex, but their relative proportions often vary markedly as a result of differences in variety, state of maturity, soil, fertilizer treatment, cultural and climatic conditions, as well as other environmental factors. The literature, pertaining to the effect of the above-mentioned factors on the chemical composition of the soybean, is voluminous and has been reported from every country in which the soybean has been grown.

Typical of these investigations may be mentioned the work

of Atasimovich, Artemieva, and Pavlova [19] who noted that the protein content decreased when soybeans were grown under irrigation. Cartter and Milner [75] found the yield of protein and oil varied with different varieties of soybeans when grown in the same locality, and also when the same variety was grown in different localities. Hall * examined a large number of soybeans, representing shipments of the 1935 crop, received at various United States terminal markets, and found that the protein content varied from 32.8 to 45.0 per cent, and the oil content from 18.5 to 22.1 per cent, calculated on an oven-dry basis. McClelland [257] examined 160 varieties of soybeans and found the oil content to vary from 13 to 23 per cent. O'Kelly and Gieger [331] observed marked variations in the content of oil, protein, nitrogen-free extract, ash, and crude fiber of the same variety of soybeans as a result of differences of maturity, crop year, and soundness of the seed, as well as similar marked differences when the same variety was compared for different crop years.

Piper and Morse [349] state that the principal varieties in the United States vary from 34.1 to 46.9 per cent in protein content.

Tsukunaga and Nishino [439] followed the changes in composition of soybeans from 53 to 54 days after blooming until time of normal maturity and found the nitrogen-free extract, crude fiber and ash content decreased with increased maturation, whereas the protein and oil content increased. Sessous [390] reported a variation in protein content from 31.7 to 41.9 per cent and in the oil content from 16.5 to 21.3 per cent for all varieties grown at Geissen from 1929 to 1936. Similar vari-

* Wallace L. Hall, *Some Analyses of Commercial Soybeans*, U. S. Bureau of Agriculture Economics, 5 pp. (1937; mimeographed).