Varietal Development and Germplasm Utilization in Soybeans

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About this report

Data in this report are presented in metric units. Monetary values have been converted to U.S. dollars. A double asterisk (**) means significant at the 1% level; a single asterisk (*) means significant at the 5% level; a cross (†) means significant at the 10% level.

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VARIETAL DEVELOPMENT AND GERMPLASM UTILIZATION IN SOYBEANS

by

S. Shanmugasundaram

INTRODUCTION

Varietal development has played a vital role in the vast expansion of the soybean area, production and utilization throughout the world, the wide variety of germplasm available to researchers having made it possible for them to develop suitable varieties for specific purposes. An understanding of photoperiod response has made possible the development of varieties adapted to specific locations, while sources of resistance to major diseases and insects have been incorporated in the development of disease resistant varieties. The nutritional value of soybeans has been well established, as demonstrated by the nutrient composition of the whole soybean and of some common soy products (Table 1).

In this paper, I will present some of the facets of soybean varietal development and germplasm utilization, in the hope that this information will be of value to those who are seeking to breed new varieties of this very important crop.

HISTORICAL BACKGROUND OF SOYBEANS

The soybean is probably one of the oldest cultivated crops grown and used by man. Ancient Chinese documents show that soybeans were widely cultivated and highly valued as a food crop long before the time of written records. In 2838 B.C., the emperor Sheng Nung first recorded the use of soybeans in a *Materia Medica* describing the plants of China. Later records repeatedly mention soybeans, which were one of the important cultivated legumes and one of the five sacred grains (the other four were rice, wheat, barley and millet) vital to the existence of the Chinese civilization.[60]* Manchuria was known as 'The Land of Soybeans', because more soybeans were grown in this country than anywhere else in the world, before the U.S.A. became involved in large scale grain soybean production in 1941. Prior to 1908, Manchuria exported its soybeans only to Japan; after this date, its soybean trade was expanded to European countries.

An Agricultural Experiment Station on the South Manchurian Railway at Kungchuling conducted selection experiments as early as 1930, and selected a variety called 'Kungchuling', with a uniform seed size and shape and an oil content of more than 20%.[60] The Manchurian Government encouraged farmers to use improved varieties and intensive cultivation techniques, by conducting crop competitions and giving prizes to the top producers. At the same time, experiment stations developed varieties for special purposes, such as bean curd, bean milk, bean sprouts, green vegetable soybeans, bean flour, oil, oil meal and various fermented products. This varietal development was basically carried out through the use of limited natural crosses and natural selections.

In Japan, vestiges of strawrope pottery of the period before Christ have been found to contain carbonized soybeans, indicating their presence and use at that time.[61] Ancient chronicles, such as *Kojiki* and *Nihonshoki*, written during the 8th century, described soybeans. In the early 1900's, Japan cultivated soybeans from Hokkaido down to Formosa (when under Japanese occupation), as the beans were one of the principal ingredients in the production of soy sauce, miso, tofu and natto. In addition

* Hymowitz[44] disagrees with this opinion, and places the domestication of soybeans about the 11th century B.C.

Table 1. Nutritional composition of soybeans and soybean products

(from Food Composition Table, Food and Nutrition Research Center, Handbook I, 4th Revision, Manila 1968)
(100 grams, Edible Portion 'E.P.')

English name	E.P.	Moisture	Food energy	Protein	Fat	Total carbohydrate	Fiber	Ash	Ca	P	Fe	Na	K	Vita. A value	Thiamine	Riboflavin	Niacin	Ascorbic acid
	%	%	cal	g	g	g	g	g	mg	mg	mg	mg	mg	I.U.	mg	mg	mg	mg
Soybeans (whole)	100	8	405	39	17	31.3	4.8	5.1	296	541	12.2	9	1540	–	0.44	0.18	2.0	+
Soybean milk	100	88	51	3	1	8.4	–	0.4	36	33	0.5	–	–	5	0.18	0.08	1.5	–
Soybean curd	100	61	109	11	6	3.6	–	17.1	86	92	9.2	8426	171	–	0.01	0.13	0.4	–
Fermented soybeans	100	52	142	14	7	8.6	2.7	18.9	176	180	8.8	5883	849	35	0.02	0.23	1.4	–
Soybean cheese (tofu)	100	84	79	8	5	1.6	–	0.7	161	83	3.2	–	–	–	0.03	0.03	0.1	+
Soybean cheese (tokwa)	100	78	107	13	7	1.2	–	1.1	152	119	1.7	14	465	–	0.04	0.03	0.1	–
Soy sauce	100	62	84	4	0	17.4	–	16.5	56	34	4.4	–	–	–	+	0.07	0.5	–
Margarine	100	6	817	0	92	1.1	–	0.6	13	+	+	–	–	2890	5.57	0.46	0	–
Tempeh (fermented soybeans)(32)		64	149	18	4	12.7			129	154	10.0			50	0.17			+
Soybean miso(27)		47		19	10	2.0						1000						

Amino acid content of soybean (in terms of 16 g N moisture-free basis)

Name	Arginine	Cystine	Histidine	Isoleucine*	Leucine*	Lycine*	Methionine*	Phenylalanine*	Threonine*	Tyrosine	Valine*
Soybeans (whole)	9.1	0.5	3.4	6.2	6.1	10.9	2.2	4.8	4.0	2.6	5.7
Soybeans (defatted)	13.8	1.0	3.7	6.5	8.4	8.9	3.2	5.6	4.1	3.4	6.6

g = gram * Essential amino acid + Trace

to the Japanese domestic production, soybeans were imported in large quantities from China and Manchuria, primarily for oil and oil cake.[65] After World War II, owing to the shortage of oils, an intensive soybean improvement program was mounted in Japan, and soybean breeding was initiated at the Hokkaido National Agricultural Experiment Station and the Saga Prefectural Agricultural Experiment Station. However, after 1961, soybean breeding at Kumamoto, Saga and Ibaragi ceased, and overall improvement research on soybeans was drastically reduced.[70]

Soybeans were introduced to and grown in Korea sometime between 30 BC and 70 AD.[52] Until 1943, farmers grew only indigenous varieties.[55] In 1923, local varieties were systematically collected and selections from them were attempted. In 1943, a variety from Japan, Yookoo 3, was released to Korean farmers as an improved introduced variety with high yield.[2]

Varieties with slender twining stems, small pods and small seeds (resembling wild soybeans rather than the varieties of China and Japan) were cultivated and used in the hilly regions of India (from the boundaries of Afghanistan, to Burma, to northern Siam and Indo-China) indicating an ancient knowledge and use of soybeans in these areas.[88] Soybeans were cultivated during the 17th century in Ceylon, Indonesia, Malaysia and the Philippines[65], the crop probably being introduced to these countries from either China, Japan or Korea; it may have been brought in by Chinese who migrated into these areas.[62;63]

Soybeans were introduced to and tried in Germany, England, France, Russia and Hungary during the 18th century.[65] Even though the utilitarian value of this crop was fully appreciated, there were no substantial increases in either area or production, mainly owing to varietal, climatological and production problems.

Soybeans were first recorded in American literature by Mease in 1804.[65] Fifty years later, in 1854, the Perry Expedition brought back one 'red' seeded and another 'white' seeded 'soja bean' from Japan.[65] Until 1898, only eight varieties were grown in this country [Ito San, Mammoth and Butterball (yellow seeded); Buckshot and Kingston (black seeded); Guelph or Medium Green (green seeded); Eda and Ogemaw (brown seeded)].[65]

In contrast with the Old World, where soybeans were considered to be a valuable food crop (grain used), until 1941, this plant was grown in the New World mainly as a forage or pasture crop. In 1923, two U.S. scientists (agrostologist C.V. Piper and agronomist W.J. Morse), who pioneered the introduction and development of soybean varieties for United States conditions, stated in the first English book on soybeans, as their opening statement, 'There is wide and growing belief that the soybean is destined to become one of the leading farm crops of the United States'. Their prediction was very true.

Early breeding work was directed to developing varieties suitable for hay, silage and pasture. By selection from introductions, varieties such as Virginia, Laredo, Otootan, Wisconsin Black, Manchu, Wilson Five, Kingwa, Peking and Ebony were released to growers.[60] Yellow seeded varieties with a high oil content which became popular were Illini, Dunfield, Mukden, Mandell, Scioto, Mansoy, Manchu, Mamredo, Delsta and Mandarin.[60]

Before the second world war, the U.S. was importing about 40% of its domestic fat and oil requirements. During the war, this supply was completely cut off, and there was an urgent need for the domestic production of oil for home consumption and for the allies. Therefore, the area of soybeans increased, production doubled and processing plants mushroomed. The increased production of cheap soybean meal with high quality protein indirectly triggered the expansion of livestock industries such as poultry farming.

The U.S. Department of Agriculture (USDA) recognized the need for a varietal development program to meet the increasing demand by farmers for new varieties. In 1936, the United States Regional Soybean Laboratory (USRSL) was established in Illinois, in cooperation with the University of Illinois;[20] twelve States in the north-central region cooperated with this laboratory, which had an agronomist and a chemist. Later, a pathologist, an entomologist, a physiologist and a nutritionist were added to the staff. The National Soybean Growers' Association was formed in 1920, and was formalized as the American Soybean Association in 1925.[43]

Privately owned pesticide companies contributed to a number of soybean production promotions by publishing valuable information, conducting crop yield contests, etc., and private seed companies commenced producing certified seed. They began their own breeding programs to supplement the research being conducted at the various state universities and agricultural experiment stations. In 1967, the Soybean Research Foundation Inc. was established in Mason City, Illinois, and adopted a winter breeding and testing program in Chile to reduce the time required to develop a variety.[1]* Varietal developments and an increasing demand for soybeans resulted in an increase both in area and yields, and soybeans became the foremost cash crop in the United States, reaching the billion dollar mark in 1967.[72]

BOTANY OF THE SOYBEAN

An understanding of the botanical aspect of a crop is a pre-requisite for any breeding and varietal development. The botanical classification and nomenclature are necessary to properly identify plant materials derived from different parts of the world, since vernacular names vary from country to country, and even within a country they differ from region to region. However, the botanical name and classification are universal. Cytological and morphological data are useful in hybridization programs.

Soybeans belong to the family Leguminosae and are botanically recognized as *Glycine max* (L.) Merrill. Their taxonomic status and nomenclatural variations are given in Table 2.

The genus *Glycine* L. includes 9 fully recognized species (Table 3). *G. soja* Sieb and Zucc. (synonymous with *G. ussuriensis* Regel & Maack) is considered to be the wild progenitor of *G. max*.[50] However, using cytogenetic evidence, Hymowitz[44] suggests that *G. max* and *G. ussuriensis* belong to the same species.

Historical, geographical and botanical evidence support the view that soybeans originated in eastern Asia, specifically the eastern half of North China.[44,62,63,65] Piper and Morse[65] and Nagata[62] consider that Manchuria was the center of origin for soybeans, but Hymowitz[44] considers Manchuria as a secondary center of genetic diversity.

The diploid chromosome number of the cultivated soybean (*G. max*) and its putative wild ancestor (*G. soja*) is 40. *G. tomentella* has both 40 and 80 forms, whereas *G. tabacina* has only 80. The 2n chromosome number of *G. wightii* is 22 or 44 in different forms.[25;44] Several workers have obtained an interspecific hybrid between *G. soja* and *G. max*.[34] This reference provides detailed information on speciation and cytogenetics.

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* At present there are over 35 private soybean seed companies in the United States (Hymowitz personal communication).

Table 2. Taxonomic status and nomenclatural history of soybeans

1. Taxonomy:

Kingdom	Plant Kingdom
Division	Spermatophyta
Subdivision	Angiospermae
Class	Dicotyledonae
Order	Polypetalae
Family	Leguminosae
Sub-family	Papilionoideae
Genus	Glycine
Species	max

2. Nomenclature:

Scientific name of cultigen and synonyms[40]:

Glycine max (L.) Merrill
Phaseolus max L.
Dolichos soja L.
Soja hispiola Moench
S. japonica Savi
S. viridis Savi
S. angustifolia Miq
Glycine hispida (Moerich) Maxim
Soja max (L.) Piper
Glycine gracilis Skvortz

3. Vernacular names of the soybean[65]

Locality (or country)	Local names	Locality (or country)	Local names
Amboina (Indonesia)	Cadeie	India (Naga Hills)	An-ing, Kije, Sudza, Tzuda, Patani-jokra
Burma (Kachin)	Lasi	India (United Provinces)	Bhat. Bhatmas, Bhatwas
Burma (Bhamo)	Lasi shapre turn	India (Bengal)	Bhetmas, Chlai, Gari-kalai, Ram kurthi
Burma (Myitkyina)	Lasi N'Loi, Lasi N'Htl	India (Punjab)	Bhut
Burma	Pe-kyat-pyin, Pe-nga-pi	India (Buthia)	Botumash, Bhativas or Bhatmais
Burma (Khasi Hills)	Ryambai-ktung	India (Santhal)	Disomhorac
Cambodia	San-dek-sieng, Sandek an gen sar	India (Sikkim)	Salyang (Selliyang), Selliangdun
Celebes (Indonesia)	Kajang koro	India	Katyang kadeleh, Patani
Ceylon (Sri Lanka)	Bhatwan, Buncae	India (N. W. provinces)	Khujoon
China (Annam)	Dau.nanh	India (Madras)	Soya mocchai*
China (Cochin)	Hoam teu	Indonesia (Java)	Katjang-boeloc, Katjang djepoen
China	Sou, Ta teou, Teou, Yeou	Italy	Soia
China (Taiwan)	Hwang teou, Maou teou* Tua tao, Ing tao	Japan	Daidzu, Daizu*, Mame
England	Soya	Korea	Kong*, Tae-too*
France	Poi oleagineux de Chine, Soia, Soja	Nepal	Bhatwas, Kajuna, Bhatmas
French Indo-China	Dau tuong	Philippines	Utaw*, Soybean*
Germany	Sojabohn	Thailand	Tua luang*
Holland	Sajaboon		
U.S.A.	Coffee bean, Japan pea, Soja, Soy, Soya, Stock pea, Soybean*		

* Author's inclusions.

Table 3. Chromosome number and geographic distribution of species in the genus *Glycine*[44]

	Species	Diploid chromosome number	Distribution
	Subgenus *Glycine* Willd		
1.	*C. clandestina* Wendl.	40	Australia; S. Pacific Islands
1a.	var. *sericea* Benth.		Australia
2.	*C. falcata* Benth.	40	Australia
3.	*C. latrobeana* (Meissn.) Benth.	—	Austral'a
4.	*C. canescens* F. J. Herm.	—	Australia
5.	*C. tabacina* (labill.) Benth.	80	Australia; S. China; Taiwan; S. Pacific Islands
6.	*C. tomentella* Hayata	40,80	Australia; S. China; Taiwan; Philippines
	Subgenus *Bracteata* Verdc.		
7.	*C. wightii* subsp. *wightii* var. *wightii* (R. Grah. ex Wight + Arn.) Verdc.	22,44?	India; Ceylon; Malaya; Java
7a.	subsp. *wightii* var. *longicauda* (Schweinf.) Verdc.	22,44?	Arabia; Ethiopia; Congo Republic to S. and W. Africa; Angola
7b.	subsp. *petitiana* var. *petitiana* (A. Rich.) Verdc.	22,44?	Kenya; Tanzania; Ethiopia
7c.	subsp. *petitiana* var *mearnsii* (De Wild.) Verdc.	22,44?	Kenya; Tanzania; Malawi; Zambia
7d.	subsp. *pseudojavanica* (Taub.) Verdc.	22,44?	E. Africa; W. Africa; Congo Republic
	Subgenus *Soja* (Moench) F. J. Herm.		
8.	*C. ussuriensis* Regel + Maack.	40	China; Taiwan; Japan; Korea; U.S.S.R.
9.	*C. max* (L.) Merr.	40	Cultigen

Soybean flowers are perfect, hermaphroditic and self fertile, and it is normally a self-pollinated crop. Studies on natural crossings have shown less than 1% out-crossing.[60,81] Soybean flowers are typically papilionaceous, and consist of two bracteoles. The tubular calyx consists of five unequal sepals which are united; the corolla is formed by a standard, two wings and two keel petals. All the petals are free. There are 10 stamens. Just before anthesis, nine stamens are pushed upward, leaving one behind.[48]

Artificial crossing for hybridization is laborious in the case of the soybean, as the small fragile flowers require care in handling. A small pair of fine tipped forceps with gentle tension and without corrugations on the inner side is preferable for emasculation. Flower buds, which would normally open the following morning, are chosen as females for emasculation, which is accomplished by first gently removing the calyx lobes and then the corolla, with the entire staminal column. It may be necessary to remove the corolla first and then remove all the anthers.[48]

The entire staminal column (with anthers) is removed from the opened flower of the male parent and used as a brush to pollinate the emasculated female parent. For successful crossing, the time of emasculation and pollination varies with season, variety and location.[48]

WORLD TRENDS IN SOYBEAN PRODUCTION

Until 1960, China dominated the world in the total area under soybeans. Although this country had 56 and 52% of the total world area during 1950 and 1960, respectively, the total production was less than that of U.S.A. After the free world trade agreement in 1961, the soybean area in U.S.A. increased tremendously, from 5.6 million ha in 1950 to nearly 21.7 million ha in 1975. Similarly, production has also increased nearly five fold during the past quarter century (Table 4).

The area planted in soybeans on the Chinese mainland increased from 9.6 million ha in 1950 to about 14.5 million ha in 1975. However, there has been no dramatic increase in production in mainland China mainly owing to the low yield per ha (there was only an 8% yield increase from 1950 to 1975 whereas, in U.S.A., there was nearly a 30% increase in yield during the same period). During the past 25 years, the worldwide soybean area has almost tripled, while production has quadrupled.

Brazil is a newcomer in the soybean industry. Even so, from only 60,000 ha she was able to produce 78,000 tons in 1950. Recognizing its yield potential capability and the world demand for oil, high protein feed and human food, Brazil quickly undertook large scale production, and today this country is one of the world's top three soybean producers. The area planted in this crop in Brazil during 1975 was less than half of that on the China mainland, but the yield was more than double, enabling the former country to produce almost as much as China.

As far as other Asian countries are concerned, particularly Indonesia (the largest producer in Asia, excluding mainland China), Korea, the Philippines and Thailand, there has been a steady increase in area as well as production (Table 4). Excluding Thailand and Taiwan, there is still plenty of room for yield improvement; even in these two countries, the average yield could be improved substantially. The major reasons for the prevailing low yields are lack of strong sustained varietal development programs, nonavailability of adapted high yielding varieties, and disease and insect problems which are unique to these areas. Another major problem is that imported soybeans are cheaper than those which are locally produced. The trend in Japan is slightly different. Instead of diverting its available rice land to soybean production, this country has decided to import almost all of its domestic soybean requirements. Local production has been reduced drastically, and the 126,000 tons produced locally are subsidized by the Government and are of the special quality required for making miso and tofu.

India has only recently developed her commercial soybean industry, following the contract between the University of Illinois and the G. B. Pant University in Pantnagar.

The enigmatic disappearance of anchovies from the Pacific and an enormous demand for feed in the U.S.S.R. pushed the price of soybeans on the international market from US$125 per mt to a record US$400 per mt in June, 1973 (Fig. 1).

The embargo placed on soybean exports by U.S.A. was a considerable blow to many Asian and European countries and caused them to identify alternative soybean sources. Extensive and intensive

Table 4. Area, production and yield per hectare of soybeans throughout the world

Country or region	1950 a			1960 a			1970 b			1975 c		
	Area (1,000 ha)	Production (1,000 t)	Yield t/ha	Area (1,000 ha)	Production (1,000 t)	Yield t/ha	Area (1,000 ha)	Production (1,000 t)	Yield t/ha	Area (1,000 ha)	Production (1,000 t)	Yield t/ha
Africa	34	15	0.4	–	28	–	43	29	0.7	199	84	0.4
Australia	–	–	–	–	–	–	–	–	–	46	64	1.4
Brazil	60	78	1.3	337	353	1.0	1,200	1,500	1.2	5,747	10,200	1.8
Europe	59	34	0.6	50	42	0.8	95	87	0.9	332	442	1.3
India	–	–	–	–	–	–	–	–	–	160	120	0.7
Indonesia	369	255	0.7	651	443	0.7	660	420	0.6	760	560	0.7
Japan	413	447	1.1	307	418	1.4	98	128	1.3	87	126	1.4
Korea	242	119	0.5	273	130	0.5	305	229	0.7	380	320	0.8
Mainland China	9,600	7,435	0.8	13,050	10,160	0.8	13,650	11,500	0.8	14,457	12,067	0.8
Philippines	–	–	1.0	2	2	0.9	1	1	0.9	3	1	0.5
Republic of China (Taiwan)	20	13	0.6	60	53	0.9	46	68	1.5	41[d]	62[d]	1.5[d]
Thailand	19	12	0.6	22	26	1.2	60	60	1.0	157	190	1.2
U. S. A.	5,587	8,144	1.5	9,573	15,113	1.6	17,177	30,910	1.8	21,693	41,406	1.9
U.S.S.R.	383	166	0.4	422	160	0.4	864	598	0.7	800	600	0.7
World	17,212	17,004	1.0	25,171	2[illegible],194	1.1	35,019	46,521	1.3	46,404	68,359	1.5

a = World Crop Statistics, FAO, Rome, 1966

b = Production Yearbook, FAO, Rome, 1970

c = Monthly Bulletin of Agricultural Economics, 1976, 25(4): 22

d = Taiwan Agricultural Yearbook, 1976. Dept. of Agriculture and Forestry, Provincial Government of Taiwan.

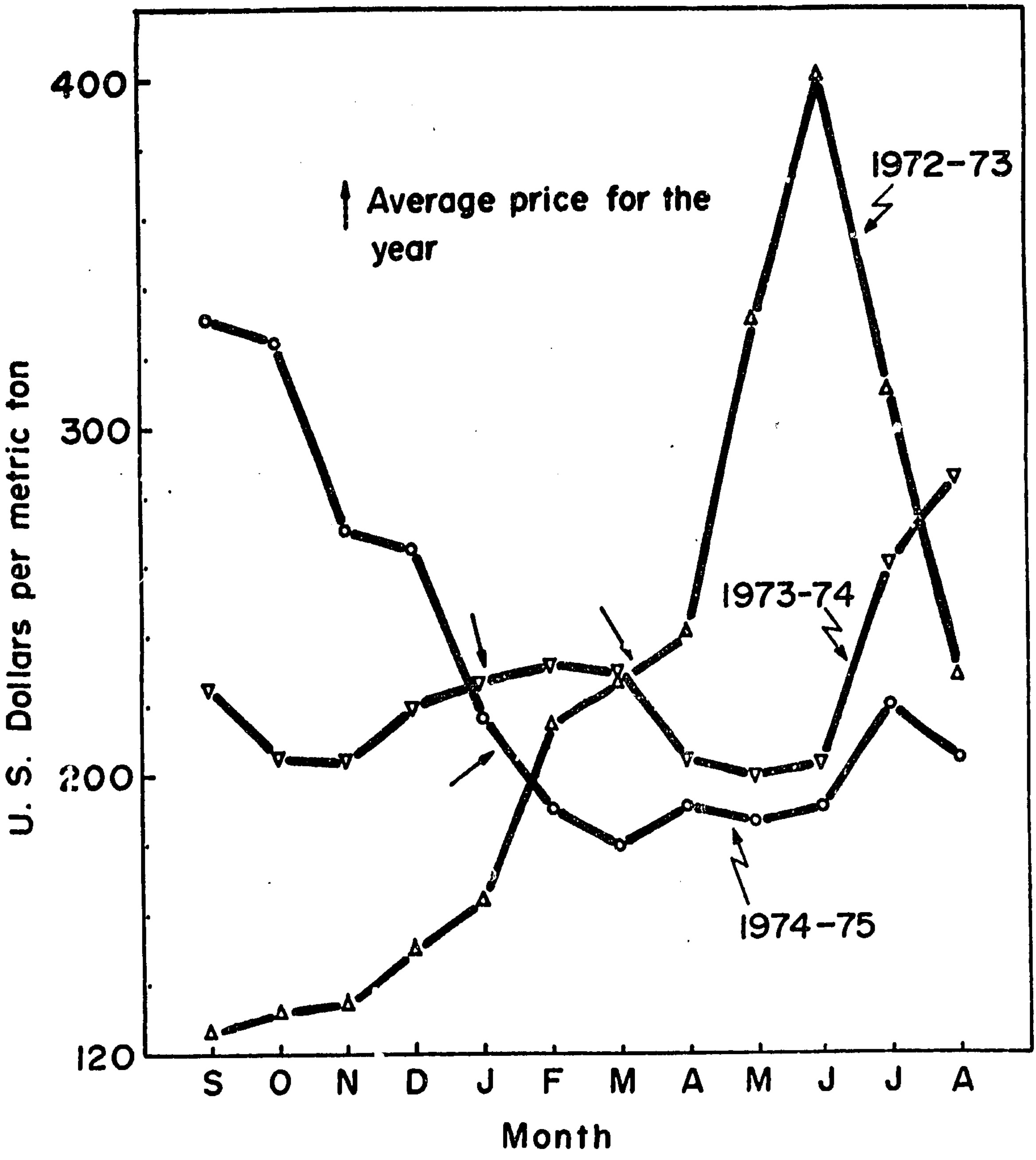

Fig. 1. Soybean grain price trends, 1972-1975

domestic cultivation and agreements with other major potential producers such as Brazil were the usual alternatives.

The production limitations of other Asian countries are mainly the lack of suitable areas of arable land, of adapted varieties and of the technology required for competitive production.

STRATEGIES IN VARIETAL DEVELOPMENT

The variation in the germplasm of soybeans is a veritable treasure chest. Even though soybeans originated in eastern Asia, their diverse use as a food and industrial commodity was exploited in U.S.A., where they were introduced and naturalized. From 1936 [when the United States Regional Soybean Laboratory (USRSL) was started in Illinois], varietal development for grain production has picked up momentum.

Among the objectives in varietal development, yield is the most important single desideratum.[65] Even today, this is *The Criterion.* Other characters considered to be important in breeding include maturity duration, non-lodging, non-shattering, high content of oil and protein and resistance to pests and diseases. Yellow seed color is an equally important attribute in the industry, since brown and black seeds produce a darker oil which is expensive to decolor. Yellow colored rather than brown or black seeds are also traditionally preferred for tofu and miso.

U. S. A.

The development of varieties has been carried out in a very systematic manner. The collection of germplasm from all over the world was followed by evaluating the collections in different locations for several years, to classify them into types adapted to specific regions, based on maturity. The study of the inheritance of both qualitative and quantitative characters, including disease or insect resistance, was initiated. Conventional breeding techniques were used to combine desirable agronomic characteristics, and new varieties were developed and released for specific locations and seasons.

It was necessary to build a firm foundation for soybean varietal development by amassing germplasm, and the large scale collection of germplasm commenced with the Perry Expedition in 1854. From only 175 varieties in 1909, the germplasm collection grew to approximately 15,000 varieties in 1944 (Fig. 2). These collections were primarily from Manchuria, Korea and Japan, and were made by Dorsett in 1924 and Morse and Dorsett from 1929 to 1931. This large collection included a number of duplicates and also a large number of U.S. forage types and types unadapted to U.S. conditions. During the process of screening, evaluation and selection for U.S. latitudes, types judged unsuitable for grain production in U.S.A. were unfortunately discarded.[68] The total germplasm in the USDA collection is now 6,100[12], of which 4,700 are at the USRSL at Urbana, Illinois, while the rest (1,400) are maintained at the Delta Branch Experiment Station, Stoneville, Mississippi.

In U.S.A. and Canada, 331 varieties have been released[45], of which 105 varieties were registered with the Crop Science Society of America from 1943 to 1974 (Fig. 3). However, breeders and soybean research workers in U.S.A. are concerned because the origin of all of these varieties can be traced back to a few accessions.[48] For instance, the following 10 varieties which were grown most widely in U.S.A. in 1971 (Wayne, Clark, Lee, Amsoy, Corsoy, Bragg, Davis, Chippewa, Beeson and Harosoy) can be traced back to only 15 accessions.[39] It is frequently mentioned that the genetic base of soybeans should be broadened to avoid genetic vulnerability to disease, insect and environmental hazards, which could cause incredible losses to both farmers and the industry.

The influence of day length on the flowering behavior of soybeans was discovered by Garner and Allard[30], who called it photoperiodism. Consequently, when soybean varieties are described according to maturity, it is necessary to include the specific latitude as a reference, otherwise the descriptions will not be true.[39]

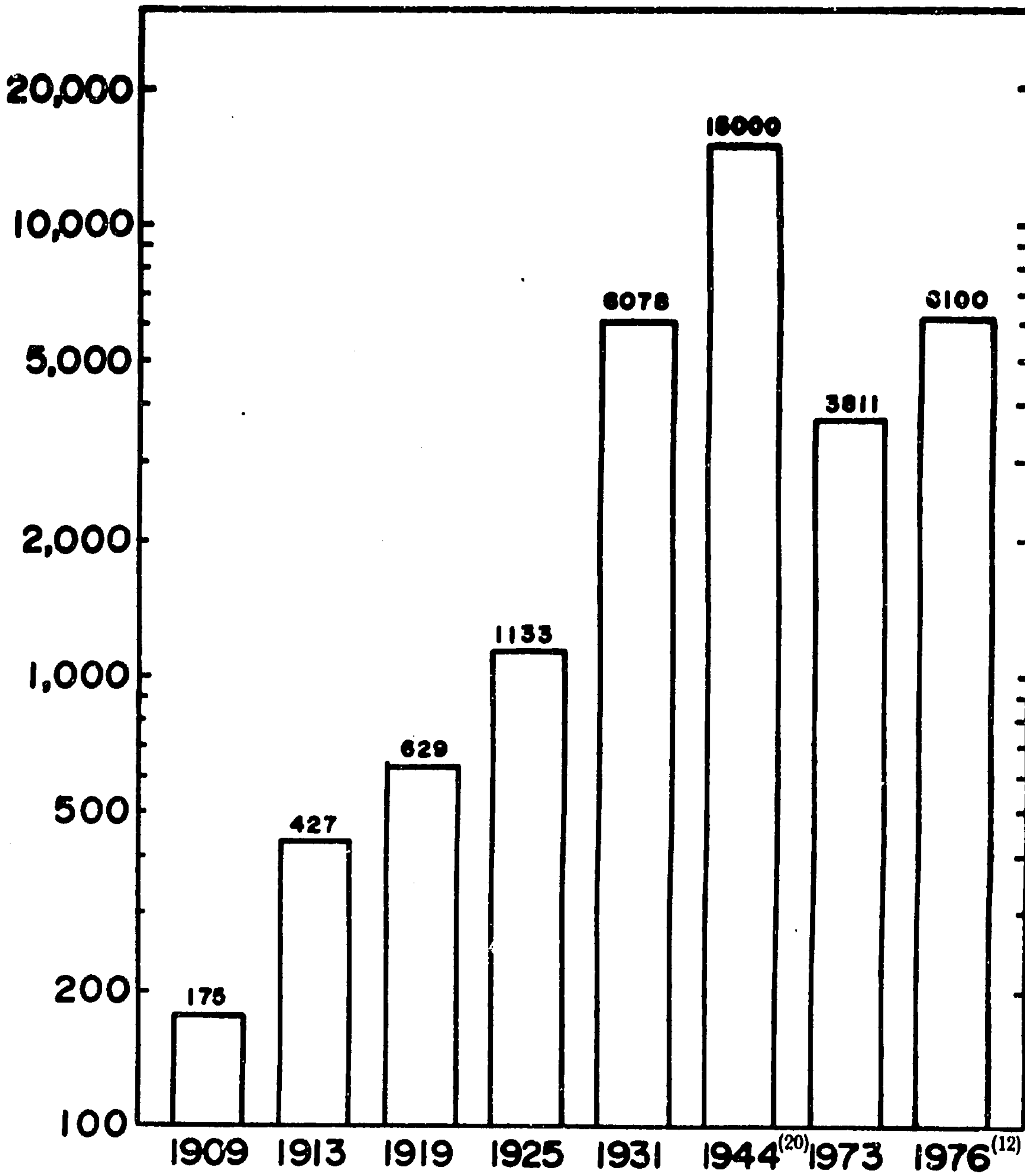

Fig. 2. Soybean germplasm introduced and developed in USA[68]

In discussing the germplasm collection, Piper and Morse[65] observed that 'the earliest varieties came from the northernmost localities, the latest from the southernmost'. To give plant breeders an understanding of varietal performance in different regions, germplasm was planted in Uniform Test Nurseries (UTN) from Canada to the gulf coast States; the varieties were classified according to days to maturity and specific area of adaptation. A variety commonly used in each test location served as a reference variety, and the maturity of the other varieties in the UTN was expressed as so many days earlier or later than the reference variety. In the beginning, the germplasm was classified into eight

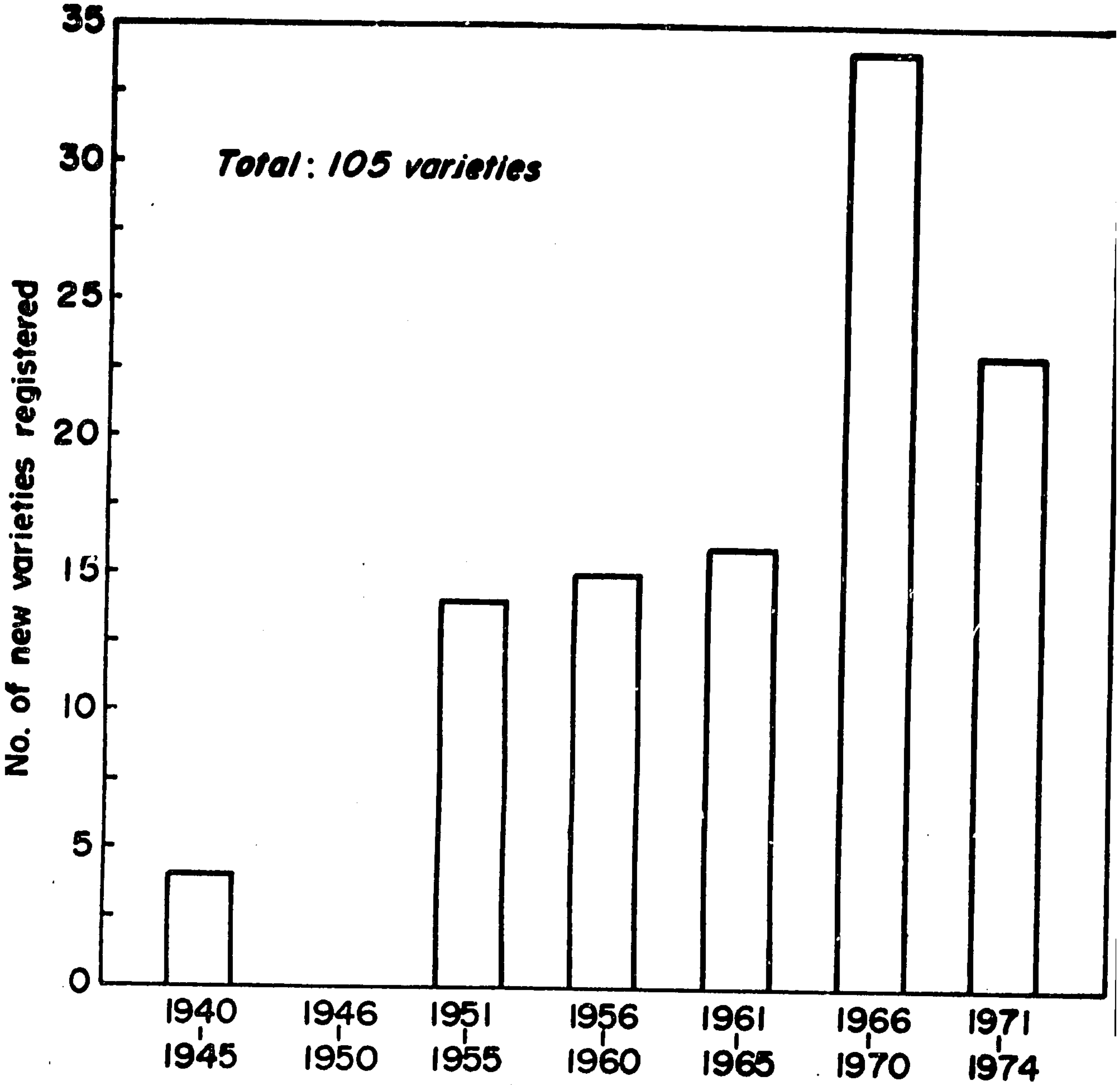

Fig. 3. Registered soybean varieties in the USA, 1926-1974[6]

groups, from 0 (early) to VII.[20] Later, on the basis of results obtained from several UTN extending from Canada to Palmira, Colombia, Bernard and Hartwig divided the germplasm into 00 (earliest maturing, adapted to northernmost latitude's longer day lengths) to group X (very late maturing, adapted to the shorter day lengths of the tropics).[37;39] This classification is very useful in U.S.A., Canada and countries located in similar latitudes. New varieties developed in U.S.A. and Canada are identified by the Maturity Group, indicating the area of adaptation.

However, when this germplasm is taken to the tropics, the Maturity Classifications and Groupings break down, and a new classification system for the tropics needs to be developed.[41;71;86;88] About

80 specific gene loci of economic importance have been recorded for soybeans, and details of this genetic research can be found in already published reviews.[13;48;83;87]

A Soybean Genetic Committee was formed in 1955 and it maintains a collection of genetic types in Illinois at the USRSL. In 1973, Bernard and Weiss listed 92 types in the collection. This collection contains genes affecting growth, morphology, reaction to nutritional factors, seed and plant composition, sterility, dwarfing, pigmentation and genes and cytoplasmic factors causing deficiencies or retention.[13] Until 1973, geneticists, breeders and agronomists in U.S.A. and other countries proposed and used 117 different gene symbols for various characters.[13] Resistance to diseases and insects are very important attributes in varietal development. Dunleavy *et al.*[26] list 30 different diseases of bacterial, fungal, viral and nematode origin which can occur or have occurred in U.S.A. They also list five nutritional disorders and four other injuries from miscellaneous causes, while, in 1975, additional diseases and disorders were described in the compendium.[5]

Of 36 infectious diseases, sources of resistance have been found for at least 10, and the inheritance of resistance has been studied in seven of them (Table 5). Varieties such as CNS, Bragg, Harosoy, Lee, Pickett, etc. are resistant to more than one disease.

An efficient varietal development program depends on the knowledge of the mode of gene action for quantitative characters. The major limitation for genetic recombination in a self-fertilised crop such as soybeans is the one imposed by linkage. To break this linkage block, it is necessary to have at least one generation of intermating (better still, three or four generations of intermating) to obtain a desirable recombination.[15]

Studies conducted by Gates *et al.*[31] showed that the following characters were governed by additive genetic variance: maturity, flowering time, period from flowering to maturity, height, resistance to lodging, seed yield, seed weight and oil percentage. Evidence provided by Brim and Cockerham[17], who fitted their estimates of genetic variance on six different genetic models, supports the presence of additive variance. When the genetic variance is all additive, the mean performance of the progenies should be the same in different inbreeding generations. Even though deviation in the mean performance of the progenies was observed, this deviation was neither large nor consistent; however, it did indicate the presence of some non-additive gene action.[17]

Heterosis in the F_1 generation has been frequently reported, and dominance in certain cases has also been indicated.[17;49;56;84;90]

Even though heritability estimates have value in estimating the genetic advance to be expected from selection, very few of these have been used in varietal development programs. A number of heritability studies have been conducted; they have been adequately reviewed by Johnson and Bernard[48] and Bernard and Weiss.[13] Heritability estimates for yield are largely affected by spacing and plant competition. As a result, the performance of individual plants in a mixed population is very biased and has a limited application.[48]

The correlation of characters other than yield as indicators of yield has so far been of little value in soybean breeding.[19;48] The reviews of correlation studies by Johnson and Bernard[48] and Bernard and Weiss[13] do not seem to offer any useful selection criteria to improve yield. The data are variable from cross to cross and in different environments. On the basis of the available data Bernard and Weiss doubt the usefulness of selection indices in soybean breeding.

Table 5. Sources of resistance to the major diseases and insects and their mode of inheritance(13;39)

Name of the disease	Resistance governed by	Sources of resistance
Bacterial Pustule [*Xanthomonas phaseoli* var *sojensis* (Hedges) Starr and Burkh]	rxp (recessive)*	CNS, Lee, Hill, Bragg, FC 31592, PI 219656
Bacterial Blight (*Pseudomonas glycinea* Coerper)	Rpg_1 (dominant)	Norchief, Harosoy, PI 132207, (race 1) PI 189968 (race 1 & 2)
Frogeye Leaf Spot (*Cercospora sojina* Hara)	Rcs_1 (dominant)	Lincoln, Wabash, CNS, Dorman, Hood
	Rcs_2 (dominant)	Kent, Lee, Ogden, Roanoke
Downy Mildew [*Peronospora manshurica* (Naum.) Syd.]	Rpm (dominant)	Kanrich, Pine Dell, Perfection, PI 166140, PI 171443, PI 174885 PI 183930, PI 200527, PI 201422
Phytophthora root rot (*Phytophthora sojae* Kaufmann and Gerdemann)	Rps (dominant)	Illini, Mukden, Arksoy**, Harosoy 63, Clark 63, Chippewa 64, Lee 68, Pickett 71, Merit, Beeson, Calland, Semmes, CNS, (in US maturity group V-X more than 40% of the strains are resistant to this disease).
Soybean Cyst Nematode	rhg_1 rhg_2 rhg_3 (complementary) and Rhg_4 (dominant)	Peking, Custer, Dyer, Pickett, Pickett 71, Mack, Ilsoy, PI 90763, PI 209332, PI 84751, PI 88788, PI 89772, PI 87631-1
Mosaic (Soybean Mosaic Virus)		Merit (resistant to seed transmission but susceptible to direct inoculation). Ogden, Hood, PI 90251, PI 92743, PI 95780, PI 96089, PI 96983, PI 148260, PI 157413, PI 170893, PI 200530
Brown Stem Rot (*Cephalosporium gregatum* Allington and Chamberlain)		PI 84496-2
Root-knot nematode (*Meloidogyne incognita acrita* Chitwood)		Laredo, Palmetto, FC 33243
Cowpea Chlorotic Mottle Virus		Bienville, Bragg, CNS, Dare, Dyer, Hardee, Hill, Lee, Pickett, Semmes, and Stuart.
Mexican bean beetle (*Epilachna varivestes* Mulsant)		PI 171451, PI 227687, PI 229358

* This gene also provides resistance to Wild fire *Pseudomonas tabaci* (Wolf & Foster) F. L. Stevens.

** Also resistant to race 3.

In terms of improvement in oil and protein content, a strong negative correlation between oil and protein has been well established by several workers.[48] Excluding this correlation, other correlation studies offer no insurmountable obstacles to yield improvement. Since the correlation data have been obtained from single F_2 plants or means of early generation lines, they are of little practical value, because selection for yield is useful only from F_4 and later generations.

The development of high yielding, disease resistant varieties which are high in oil and/or protein content is the major breeding objective in U.S.A. Equally important are resistance to lodging and resistance to shattering. A large seed size is required for vegetable soybeans. However, vegetable varieties suitable for breeding are limited.

The soybean is an inbreeder, and the breeding methods used are similar to those used for autogamous species. Widely used methods are: introduction, selection from introductions (pure line selections), hybridization and selection using either the pedigree, bulk or modified bulk pedigree method, back crossing, and a modified pedigree method (single seed descent – SSD). Any plant material brought in from another country, which is acclimatized to local conditions and multiplied for seed, is called an introduced variety. Selection may be done within the introductions and these selections may prove to be better than the original introduction in one or more characters. This is possible, especially when the introduction is a heterogeneous mixture. Dunfield, Illini, Macoupin, Manchu, Mandarin, Mandel, Mukden, Richland and Scioto are a few examples out of the total 37 grain varieties released until 1939.[60] In hybridization and selection, bulk, pedigree, bulk-pedigree, back cross and SSD methods are used.

The bulk method takes advantage of between and within line variance, and selection is postponed until the F_6 or later generations, and is based on individual plant variability.[28] This method is not extensively used in soybean breeding.[15] There are two stages of selection in the pedigree method, which are carried out independently between and within line components of genetic variance. Selection for simply inherited characters during early generations may be employed efficiently with justification. Since the heritability value of yield is low, selection for yield in the early generation is not advisable. It has been argued that, for characters with low heritability, the bulk breeding method is useless, unless yield is correlated with some character with high selective value. Available information reveals that days to maturity, number of pods and beans per plant are highly correlated with yield[82]; this justified the use of the bulk method.[28] A comparison between bulk and pedigree methods of breeding, using F_6 lines from six crosses, obtained essentially similar results for yield, plant height, lodging, oil and protein content of seed.[78]

The 10 most widely grown varieties in U.S.A. in 1971, namely Wayne, Clark, Lee, Amsoy, Corsoy, Bragg, Dare, Chippewa, Beeson and Harosoy, are all derived from hybridization and selection, either by the pedigree or bulk method.

The back-crossing technique is extensively used to transfer simply inherited resistance to plant diseases and nematodes to otherwise desirable varieties. The source of resistance is normally an unadapted, genetically diverse type and it is used as a non-recurring parent in the cross. Back-crossing is done to the adapted recurrent parent and, after one or two back crosses from a large F_2 population, the desirable recurrent parent types are selected. Some of the varieties developed by this technique are Clark 63, Harosoy 63, Chippewa 64, Lee 68, Amsoy 71 and Pickett 71.

The SSD method utilizes additive genetic variance and obligate self-pollination. In this method, each F_2 plant in the population is advanced by SSD[14;33] until the F_4 or F_5 generation, and then these plants are tested in progeny rows for selection. This technique is considered to be superior to other methods[28;51], but no varieties developed by this technique have so far been released.

When crosses are made to form a hybrid population, we are placing our trust on two candidates from a population of homozygous individuals, which are thoroughly inbred. Thus, any improvement on these genotypes has a strait (limited) genetic base.[36] The use of diverse germplasm and three way crosses with the adapted variety and exotic materials was suggested to broaden the genetic base.[38;48;77] Hartwig[38] indicated the necessity of using one or more back crosses to the adapted parent to retain productivity and adaptation to the environment, while employing the diverse germplasm.

Hybridization between cultivated *G. max* and wild *G. soja* has been carried out with a view to improving the protein content in soybeans, by using *G. soja* as the non-recurrent parent.[39] Highly productive lines with a high protein content have been developed, and improved varieties should be forthcoming from these.

Sterility in soybeans has been reported by several scientists.[21;35;64;67;75] Brim and Young[18] discovered an example of complete male sterility which is governed by a single recessive gene ms ms; this has provided hope for the development of hybrid soybeans.

Male sterility is controlled only by genes, and there is no cytoplasmic sterility as in maize, to enable easy hybrid seed production. The strategy with soybeans, therefore, is to plant male sterile and male fertile pollinators side by side and to use insects to pollinate the male steriles. We do not as yet have hybrid soybeans.[16]

In 1924, the average yield of soybeans in U.S.A. was 0.7 t/ha[41]; in 1975, this figure had reached an all time high level of 1.9 t/ha (Table 4), because of the varietal development which has taken place during the past half century. However, this is not the maximum yield potential of soybeans and national yield contest winners have demonstrated the yields that may be obtained. The varieties that were used by the National Soybean Yield Contest Winners are listed in Table 6, along with their yields and the average yields obtained either in the Uniform Test Nursery or in varietal trials. Clark 63, Bragg, Ford, M-1, Lee and Wayne have consistently produced more than 5 t/ha, with Clark 63 and Ford recording a maximum of 6.3 t/ha. It is obvious from Table 6 that, regardless of the maturity class to which the varieties belong, it is possible to obtain the maximum yield. Neither location, latitude nor photoperiod will be a deterrent factor for high yield as long as we have the right variety and everything else to go with it.

Japan

In 1935, soybean breeding in Japan was started on a small scale at experiment farms at Odate, Ishioka, Akita, Ibaragi and Kumamoto. The breeding program was intensified by the inclusion of Saga in 1947, Hokkaido and Tokachi in 1956 and Nagano in 1957. The Japanese soybean germplasm collection is stored in a computerized system at the National Institute of Agricultural Sciences in Hiratsuka. At present they have 1,472 entries in their collection. This storage facility was established only in 1965.[3] The major objective is to develop high yielding varieties suitable for mechanized planting and harvesting, with a high protein content and carrying resistance to soybean dwarf virus, cyst nematode and cold weather. In addition to conventional pureline selection, artificial hybridization, bulk, back cross and pedigree methods of breeding, radiation breeding was started on a large scale in 1957-58.[29]

Table 6. Soybean varieties demonstrating high yield performances in U.S.A.

Variety name	U.S. maturity group	Mean yield[6] (t/ha)	Highest yields* (t/ha)	Year registered
Bragg	VII	2.6	6.0, 4.6, 4.2	1964
Clark 63	IV	3.3	6.3, 6.2, 4.8, 4.7, 4.6	1963
Ford	III	2.5	6.3	1960
Harosoy	II	2.5	4.3	1955
Harosoy 63	II	3.2	4.6	1964
Lee	VI	2.1	5.5, 5.3	1958
M – 1	—	—	6.2	—
Shelby	III	2.4	4.5	1960
Traverse	0	2.3	4.3	1966
Wayne	III	3.4	5.0, 4.7	1966

* Soybean Digest, various issues.

From 1935 to 1968, remarkable progress was made in developing 50 new varieties. Outstanding among these were Raiden, Koganejiro, Higomusume, Tokachinagaha, Miyakishirome, Hakuho 1 and Saikai No. 20. Raiden was the first variety obtained by irradiation of the parent variety Nemashirazu with Co^{60}. Maturity was reduced by 25 days by irradiation.[29] During 1970, 54 different improved varieties were cultivated in 10 prefectures.[53] The best yielders in Japan are shown in Table 7, in which a record yield of 7.8 t/ha from 13,330 hills/ha was obtained in 1960 in Miyaki from the variety Miyakishirome.

Table 7. Yield performances of Japanese varieties in Japan[53;58]

Location	Year	Variety	Yield (t/ha)	No. of hills/ha
Miyagi	1960	Miyakishirome	7.8	133,300
Iwate	1962	Tokachinagaha	7.6	400,000
Miyagi	1963	Hokuho 1	7.3	288,900

Republic of China (Taiwan)

Taiwan's varietal improvement program commenced in 1953.[22] During 1960, Chan of the Taiwan Agricultural Research Institute was able to obtain 3,000 accessions from USRSL at Urbana, Illinois.[23] This germplasm collection was planted during 1961 and evaluated for 15 different characters, specific attention being paid to identifying sources of resistance to soybean rust disease (caused by *Phakopsora pachyrhizi*). The accessions were screened during the spring and summer seasons and selections were made, based on maturity, yield, suitability for use as a green vegetable or for forage, resistance to lodging, increased number of seeds per pod and resistance to diseases. The selections are listed in Table 8. Of 2,907 accessions which have been screened, 2.4% (or 70 accessions) have been selected for the breeding program.

Table 8. A list of accessions selected from germplasm screening for crossing and developing new varieties in Taiwan[23]

	Accessions selected	Basis of selection
I	PI 180519*, PI 180521, PI 180525, PI 232998*, FC 30684, PI 180524, PI 231172, PI 232997, PI 180517	High yield, early maturity
II	PI 91100, PI 86465, PI 817-Ped-G, PI 85989-Ped, PI 170892, PI 81042-Ped-1, PI 54610-3-2-B, LX 1166-32, PI 84669-Ped, PI 88820, D 633-15, Nansemond	High yield
III	Osaya, PI 82555, FC 19979, FC 19976 (yellow seeded); PI 85272, PI 196149, PI 124871, (black seeded); PI 96193, PI 153210** (brown seeded); Giant Green, PI 243533 (green seeded); PI 132217 (reddish brown seeded); PI 179823** (mottled)	Green vegetable types
IV	PI 165957, PI 174860, PI 175175, PI 175190, PI 175176, PI 181696, PI 175177, PI 175178, PI 175184, PI 181697, PI 209340, PI 209577, PI 209578, PI 209834, PI 222549, PI 222550, PI 239236, PI 239237, PI 174854, PI 165538, PI 175180, PI 222546, PI /4859, PI 66048, and PI 75182	Forage types
V	FC 810[illegible]9	Resistant to lodging
VI	PI 200492, PI 200490, PI 200451	Resistant to soybean rust
VII	PI 181537, PI 227564, PI 79583, PI 86026, PI 86029, PI 96321 and T_{41}	Greater number of seeds per pod

* Highest yielders

** Best vegetable types

The major breeding objectives in Taiwan have been: a) wide adaptability, with minimum sensitivity to photoperiod and temperature, b) early maturity, so that the variety can be used in multiple cropping systems, c) resistance to soybean rust, and d) high yield.[22]

Introduction and acclimatization, pureline selection, hybridization and selection and mutation breeding are basic methods employed in varietal development. The bulk method has been the most widely used technique. To minimize sensitivity to photoperiod and temperature, the 'disruptive seasonal selection' technique has been adopted.[57;79;80] Since soybeans can be grown practically all the year round in Taiwan, breeders were able to repeatedly select from successive generations grown in different seasons. Since world germplasm did not provide many diverse sources of resistance to soybean rust, mutation breeding, using X-ray and neutrons, was also tried, but with little success.[57] Varieties released from various sources are indicated in Table 9. Nearly 73% of 136 soybean farmers surveyed in Taiwan grew the Shih-Shih, Wakajima or Palmetto varieties.[11] Although nearly 70 different accessions have been identified (among these, 25 were forage types), only PI 200492 has been used in the hybridization program, primarily because of the seriousness of soybean rust disease, and no back crossing has been done, owing to the lack of rust-screening techniques.

Table 9. List of varieties introduced, developed and in use in Taiwan

Name of variety	Year released	Introduced from or pedigree	Yield t/ha Average	Yield t/ha Maximum	No. of* tests	Remarks
Sankuo	1956	Japan	1.1	2.7**	13	Tolerant to wet soil
Palmetto	1957	USA	2.3	3.4**	4	
Shih-Shih	1957	Japan	1.7	4.0(9)	1	Early, wide adaptability
Wakajima	1960	Japan	2.3	3.7**	9	Late, wide adaptability
T. K. No. 5	1963	Greenbean /Wakajima	1.5	3.2**	19	Early, wide adaptability
Chung Hsing No. 1	1964	Huang Pao Chu /Greenbean// Wakajima	2.1	2.8(80)	1	
Chung Hsing No. 2	1965	Huang Pao Chu /Greenbean	2.3	2.8(80)	1	
Chung Hsing No. 3	1965	Nungyuan 1/ Yonedake	2.7	3.6(80)	1	
Tainung No. 3	1968	PI 200492 /Nungshi H.11	1.6	4.1**	10	Early, rust tolerant
Tainung No. 4	1970	PI 200492 /Nungshi H.11	2.0	3.3**	4	Early, rust tolerant
Kaohsiung No. 3	1971	PI 200492 /Shih-Shih	1.9	3.4**	21	Rust tolerant, wide adaptability

* Number of tests refer to average yield

** Annual reports of dryland food crop improvement series No. 1, 10, 12 and 14 (1959-60, 1970, 1972, 1974)

The average soybean yield in Taiwan today is comparable with the world average (Table 4). The maximum yield potential of all the improved varieties is about 3 t/ha or more, and it is important to note that these high yields are obtained in about 100 days, compared with 130 to 140 days in the temperate zones. Considering the yield potential of these entries, the average in the regional trials is fairly good (Table 9). Since the incorporation of soybean rust tolerance, early maturity and adaptability have been primary objectives, yield potential has not been completely exploited.

INTERNATIONAL PROGRAMS

Illinois – India

As part of the land grant university development program, a research project on soybeans, using a team approach, was started in 1965 with ICAR (Indian Council for Agricultural Research) at the G. B. Pant University of Agriculture and Technology (Pantnagar, U.P. India) and at Jawaharlal Nehru Agricultural University (Jabalpur, M.P. India). USAID, the University of Illinois and the Indian Ministry of Agriculture cooperated in this program until 1973. A package of techniques was supplied along with the seed and, in 42 plantings, yields ranged from 1.0 to 3.8 t/ha.(41)

The whole of the USDA germplasm collection was planted, evaluated and screened, and selections were made for a breeding program. Singh was able to identify sources of resistance to yellow mosaic virus and soybean rust.(73) Processing and marketing units were incorporated with the production units. This resulted in the rapid popularization of new high protein soy products such as soymilk and nutri-nuggets through the intensive education of the public.

Although the Illinois and USAID programs were phased out in 1973, they helped to create a sense of awareness for soybeans, and today there is a strong All India Coordinated Soybean Research Project, with assistance from ICAR. With its present momentum, further progress in the expansion of area and increase in production may be expected through varietal development.

Asian Vegetable Research and Development Center (AVRDC)

AVRDC is the first international agricultural research center to pay major attention to soybean varietal development specifically for tropical conditions. The sensitivity of soybeans to short days and high temperatures makes varieties adapted to temperate climates unsuitable for cultivation in the tropics. Specific disease problems such as soybean rust (which is not present in temperate countries) are unique to tropical areas. Multiple cropping systems and the potential to grow several crops throughout the year impose specific requirements for varietal development.

The objective of AVRDC is to collect soybean germplasm throughout the world and develop high yielding varieties which are adaptable and acceptable to farmers in the tropics. The incorporation of resistance to diseases and insects is a further objective.(59) AVRDC has a strong foundation in its germplasm collection, which has increased from 3,064 in 1973 to more than 9,000 in 1975.(9;10;11) There are about 1,000 accessions which are duplicates.

The identification of photoperiod insensitivity in the germplasm, an understanding of its inheritance pattern and its role in controlling yield components, and the utilizing of this type of information to develop adapted, productive types is the goal of AVRDC. Considerable progress has been made in identifying germplasm with high yield and photoperiod insensitivity (Table 10). Moderate resistance to soybean rust was found in a field screening of 1,080 accessions from Stoneville, Mississippi, U.S.A. (Table 11). Sources of resistance to soybean mosaic virus, purple seed stain and nematodes have also been identified (Tables 12, 13, 14, respectively). As the result of a field screening, a few accessions were found to be less preferred by bean fly (*Melanagromyza* sp.) (Table 15). High yielding selections from the AVRDC breeding program, together with their yields, are presented in Table 16. One of the selections was able to give a computed yield of 7 t/ha.

Table 10. Top ten germplasms selected for high yield potential at AVRDC in Taiwan[10;11]

AVRDC acc. no.	Variety name or P.I. number	Yield (t/ha)		Days to maturity	
		1974	1975	1974	1975
20	66-G-3	3.3	3.0	93	102
74	Taichung E-32	3.5	2.4	95	98
86	Clark 63	3.5	3.5	91	106
215	PI 194647*	2.8	2.8	89	88
239	Hardome	3.0	2.4	89	86
882	PI 89170*	3.6	2.6	89	94
1322	PI 248407*	3.7	3.0	95	89
1340	FC 19979-6	3.0	3.2	95	98
1612	PI 85089-Ped	3.2	3.2	102	106
2120	PI 86736	7.0	2.0**	106	110

* Photoperiod insensitive.

** Crop damaged by typhoons Nana, Rita and Betty.

Table 11. Soybean cultivars identified as being moderately resistant to soybean rust*[11]

AVRDC acc. no.	P.I. number	Origin
7985	PI 60273	China
7988	PI 62204	China
8260	PI 90406	China
8268	PI 94159	Japan
8283	PI 159322	Korea
8316	PI 181561	Japan
8377	PI 371609	China
8586	PI 230970	Japan
8587	PI 230971	Japan

* 1,080 cultivars were tested in the field and the plants were inoculated twice.

Table 12. Soybean cultivars identified as being resistant to soybean mosaic virus*(10)

AVRDC acc. no.	Varietal name or P. I. number	Origin
38	Shih Shih	Japan
171	PI 159764	Korea
260	PI 153241	Belgium
270	PI 153262	Belgium
288	PI 180501	Germany
311	PI 189898	France
358	PI 248403-1	Unknown
394	Norsoy	U.S.A.
452	PI 84668	Korea
453	PI 84668	Korea
519	PI 153263	Belgium
1096	PI 80461 201	Japan
1200	PI 89109	Japan
1501	PI 157409	Korea
1601	PI 62204-1	China
2021	PI 230973	Japan
2042	Tainung No. 3	Taiwan

* 1,883 cultivars were field-screened. Field-resistant entries were again tested 5 times with artificial inoculations, both in the field and in the greenhouse.

Table 13. Soybean cultivars identified as being resistant* to purple seed stain**(11)

AVRDC acc. no.	Varietal name	Origin
82	Harosoy	Philippines
108	Palmetto	Philippines
139	Hidatsa	Japan
352	PI 248400	Unknown
540	PI 181537	Japan
569	PI 200508	Japan
967	PI 200479	Japan
1550	PI 238926	Unknown
1923	White Biloxi	U.S.A.
2007	Giant Sleeves	Taiwan
2014	Kaohsiung No. 3	Taiwan
2038	Lee	U.S.A.
2069	Sumbing	Indonesia
2110	Acadian	U.S.A.
2201	Pochal	Korea
2247	No. 208	Korea
2261	H 15	Taiwan
2527	L-206-4-m(2)-10-m(6)	Colombia
2659	Fukuzu	Japan
2662	Austin	Japan
2704	Ross	Japan
2721	Shin 2	Japan
2724	Takiya (Waseshu)	Japan
2748	KO 309	Japan
2791	Bikuni	Japan

* Less than 1% seed with purple seed stain.

** 1,200 accessions screened in 1974 and 1975.

Table 14. Soybean cultivars identified as being resistant to root-knot nematodes in Taiwan[11]

AVRDC acc. no.	Varietal name	Origin
81	Hill	U.S.A.
87	Bragg	U.S.A.
88	Bethel	U.S.A.
108	Palmetto	U.S.A.
123	Hampton	U.S.A.
383	Habaro	U.S.S.R.
1673	Armredo	U.S.A.
1715	PI 86091-Ped	Japan
2024	D69-9801	U.S.A.
2033	Laredo	U.S.A.

Table 15. Soybean cultivars identified as being less preferred by beanfly[11]

AVRDC acc. no.	Varietal name	Origin
48	Wilken	U.S.A.
51	Clay	U.S.A.
82	Harosoy	U.S.A.
2023	PI 227687	U.S.A.
2092	888 Klung Kung	Indonesia
2096	887 Gendah Slay	Indonesia
2146	1390 DHS	Indonesia

Table 16. Top ten selections with high yield potential from AVRDC breeding lines[11]

Line designation	Parentage	Yield (t/ha)	Days to maturity
30094-1-10-0	66-G-3/PI 200492	3.0	100
2120	Selection from PI 86736	7.0	106
KS 584	Selection from KS 584	3.7	105
KS 535	Selection from KS 535	4.1	99
KS 628	Selection from KS 628	4.1	109
30094-1-55	66-G-3/PI 200492	3.5	105
30094-1-42	66-G-3/PI 200492	3.5	107
30222-2-7	66-G-3/Shih Shih	3.5	104
30264-0-9	Shin 2/KS 535	3.4	100
30106-1 17	TN No.3/Bansei kuro daizu	3.4	109
30094-1-32	66-G-3/PI 200492	3.3	108
30073-2-19	Shakkin Nashi/CH No. 3	3.2	96
30105-2-18	Tainung No. 4/Shiro Daizu	3.1	106
Check cultivar	Shih Shih	2.2	90

International cooperation through AVRDC's Outreach Program (such as the ones in the Philippines and Korea) or directly through national programs (such as with the oil crop project of the Department of Agriculture in Thailand) are signs of future prospects for increased production. AVRDC has also signed a memorandum of understanding for cooperation with the International Soybean Program and it is also cooperating with other international centers, such as the International Institute for Tropical Agriculture, Centro Internacional de Agricultura Tropical and the International Rice Research Institute, to integrate and consolidate researches and avoid duplication of research areas. This will also enable researchers to develop crops suitable for a cropping system.

Production and research training programs are an integral part of the AVRDC, which help to train participants from different countries and give them the technical expertise needed for the national programs. Upon their return to their own countries, these participants will serve as vital links between the Center and the national programs.

Program for International Research, Improvement and Development of Soybeans (PIRIDS) – International Soybean Resource Base (INTSOY)

With USAID/csd-3292, the University of Illinois commenced a PIRIDS in 1971; at the end of March, 1973, the name was changed to INTSOY. In 1972, an international soybean variety experiment was conducted by PIRIDS at 20 locations in 11 countries using high yielding U.S. soybean varieties. During 1973-74, the test sites were increased to 90 and the number of countries to 33. Twenty varieties were used in these ISVEX trials, which were sent at the request of cooperators; this indicates the growing interest of these countries in producing soybeans.

The ISVEX trials revealed an important lesson, since some of the U.S. soybean varieties yielded more than 4 and 5 t/ha under tropical and sub-tropical conditions (Table 17). Out of the 28 varieties, all except 7 proved their potential in more than one location, and their performances indicated the possibility of beginning on a better operational basis. The introduction of disease resistance and early maturity will result in further improvements being made, using these high yielding varieties as the basic materials.

INTSOY has a very strong, talented and experienced team of researchers, and has the advantage of being associated with the University of Illinois and the University of Puerto Rico, Mayaguez Campus, the latter location serving as a winter nursery for temperate zone varietal development. INTSOY has a training program, publishes valuable information as an INTSOY series and organizes international meetings in cooperation with other international and national programs. During 1976, AVRDC cooperated with INTSOY and the Government of Thailand in sponsoring a conference on 'Expanding the Use of Soybeans for Asia and Oceania' at Chiang Mai, Thailand.

International Institute for Tropical Agriculture (IITA)

The soybean program at IITA started in 1970 and is receiving minor emphasis in their Grain Legume Improvement Program. Its primary purpose is to meet the needs of African countries and the major objectives are breeding for high yield, good seed quality, non-shattering, non-lodging and 'environmental insensitivity'.[46;47;69] The basic principles employed should result in the development of valuable varieties for tropical locations, in countries with similar environmental conditions as those in Africa. Recently, IITA has collaborated with INTSOY in distributing ISVEX trials on INTSOY's behalf in African countries. The major problem in the development of soybeans in Africa is not in production, but in gaining the acceptance of growers and consumers. If suitable industries can be developed, there is a vast potential for soybeans in Africa.

Table 17. Varieties with a yield potential of over 4 t/ha in the ISVEX trials during 1974 and 1975.

Variety	Site	Country	Latitude	Elevation (m)	Yield (t/ha)	Days to maturity
Amsoy 71	Karaj	Iran	36° N	1300	4.7	104
	La Platina	Chile	33° 34′ S	625	4.0	138
	Novi Sad	Yugoslavia	45° 20′ N	80	4.7	139
	Sassari	Italy	40° 43′ N	80	4.7	144
Beeson	Karaj	Iran	36° N	1300	4.3	110
	Novi Sad	Yugoslavia	45° 20′ N	80	4.7	139
	Sassari	Italy	40° 43′ N	80	4.3	144
Bonus	Karaj	Iran	36° N	1300	4.8	132
	Khumaltar	Nepal	27° 40′ N	1360	4.3	100
	Thirunelvely	Sri Lanka	9° 6′ N	1	4.8	105
Bossier	Boliche	Ecuador	2° 21′ S	17	4.6	104
	Kilinochchi	Sri Lanka	9° 2′ N	9	5.2	94
	Maracay	Venezuela	10° 14′ N	450	5.4	109
	Thirunelvely	Sri Lanka	9° 6′ N	1	4.4*	94
	Thirunelvely	Sri Lanka	9° 6′ N	1	5.4**	105
	Papeete	Tahiti	17° 30′ S	2	4.9	111
Bragg	Abapo-Izozog	Bolivia	18° 30′ S	389	4.3	103
	Kilinochchi	Sri Lanka	9° 2′ N	9	4.3	92
	Portoviejo	Ecuador	1° 4′ S	44	4.1	91
	Thirunelvely	Sri Lanka	9° 6′ N	1	5.7	105
Calland	Boliche	Ecuador	2° 21′ S	17	4.1	98
	Karaj	Iran	36° N	1300	4.9	132
	Portoviejo	Ecuador	1° 4′ S	44	4.4	98
Clark 63	Karaj	Iran	36° N	1300	4.5	132
	Kilinochchi	Sri Lanka	9° 2′ N	9	4.3	92
	Thirunelvely	Sri Lanka	9° 6′ N	1	5.7	91
	Sassari	Italy	40° 43′ N	80	4.0	139
Columbus	Portoviejo	Ecuador	1° 4′ S	44	4.4	98
Corsoy	Karaj	Iran	36° N	1300	4.6	110
	Novi Sad	Yugoslavia	45° 20′ N	80	4.7	139
	Sassari	Italy	40° 43′ N	80	4.0	139
Davis	Abapo-Izozog	Bolivia	18° 30′ S	389	4.4	92
	Kilinochchi	Sri Lanka	9° 2′ N	9	5.4	99
	Portoviejo	Ecuador	1° 4′ S	44	4.2	96
	Thirunelvely	Sri Lanka	9° 6′ N	1	5.0	98
	Papeete	Tahiti	17° 30′ S	2	4.9	111
Forrest	Thirunelvely	Sri Lanka	9° 6′ N	1	5.3	97
	Papeete	Tahiti	17° 30′ S	2	4.9	111
Hampton 266A	Chiapas	Mexico	14° 54′ N	40	4.9	96
	Portoviejo	Ecuador	1° 4′ S	44	4.2	91
	Kilinochchi	Sri Lanka	9° 2′ N	9	4.5	93
	Thirunelvely	Sri Lanka	9° 6′ N	1	5.2	110

(Table 17 – con'd)

Variety	Site	Country	Latitude	Elevation (m)	Yield (t/ha)	Days to maturity
Hardee	Boliche	Ecuador	2° 21′ S	17	4.1	105
	Portoviejo	Ecuador	1° 4′ S	44	4.3	96
	Kilinochchi	Sri Lanka	9° 2′ N	9	5.2	94
	Thirunelvely	Sri Lanka	9° 6′ N	1	6.0	113
Hark	Novi Sad	Yugoslavia	45° 20′ N	80	4.1	145
	Sassari	Italy	40° 43′ N	80	4.4	145
Hill	Abapo-Izozog	Bolivia	18° 30′ S	389	4.1	98
Hodgson	Novi Sad	Yugoslavia	45° 20′ N	80	4.3	129
	Sassari	Italy	40° 43′ N	80	4.4	124
Improved Pelican	Kilinochchi	Sri Lanka	9° 2′ N	9	4.8	98
	Thirunelvely	Sri Lanka	9° 6′ N	1	4.4	93
Jupiter	Abapo-Izozog	Bolivia	18° 30′ S	389	4.1	134
	Boliche	Ecuador	2° 21′ S	17	4.3	112
	Palmira	Colombia	3° N	1000	4.5	103
	Mansehra	Pakistan		1080	4.9	129
	Maracay	Venezuela	10° 14′ N	450	5.5	109
	Thirunelvely	Sri Lanka	9° 6′ N	1	4.2	106
	Kilinochchi	Sri Lanka	9° 2′ N	9	4.6	113
	Thirunelvely	Sri Lanka	9° 6′ N	1	4.4	125
	Port of Spain	Trinidad and Tobago	11° N	6	4.1	100
Jupiter/F-67-1533	Mon Repos	Guyana	6° 46′ N	1	4.1	124
Lee 68	Swat	Pakistan	34° N	1200	4.5	140
PB-1	Thirunelvely	Sri Lanka	9° 6′ N	1	4.4*	87
	Thirunelvely	Sri Lanka	9° 6′ N	1	5.7**	91
Semmes	Papeete	Tahiti	17° 30′ S	2	4.4	118
S. J. 2	Thirunelvely	Sri Lanka	9° 6′ N	1	4.3*	93
	Kilinochchi	Sri Lanka	9° 2′ N	9	4.5	95
	Thirunelvely	Sri Lanka	9° 6′ N	1	4.1	105
Tracy	Thirunelvely	Sri Lanka	9° 6′ N	1	4.9	97
Valu Vatmas	Khumaltar	Nepal	27° 40′ N	1360	4.1	100
Wells	Novi Sad	Yugoslavia	45° 20′ N	80	4.2	146
	Sassari	Italy	40° 43′ N	80	4.3	144
Williams	Bet Dagan	Israel	32° N	80	4.2	112
	Karaj	Iran	36° N	1300	4.4	132
	Sassari	Italy	40° 43′ N	80	4.3	137
	Swat	Pakistan	34° N	1200	4.5	140
	Thirunelvely	Sri Lanka	9° 6′ N	1	4.2*	84
	Thirunelvely	Sri Lanka	9° 6′ N	1	5.1**	95
Woodworth	Sassari	Italy	40° 43′ N	80	4.7	144

(Source: Whigham, 1975 and personal communication)

* 1974 trials ** 1975 trials

Thailand – Japan

In 1970, the Japanese Government provided assistance to the Thailand soybean project. A resident scientist from Japan was stationed in Thailand to help organize and conduct breeding research, in close association with national scientists. In about three years, the team was able to assemble from 18 different countries a germplasm collection of 1,680 entries. Data have been collected for nine characters, for both rainy and dry seasons, and these have been catalogued for future reference.(54) Although this program was terminated at the end of 1975, the national program has been strengthened and continues to have the informal cooperation of Japan. Prior to the Thailand-Japan project, the Thailand soybean project released three soybean varieties through hybridization and selection (S.J. 1, S.J. 2 and S.J. 3). S.J. 1 and S.J. 2 are both very popular with farmers, and as the result of the use of these varieties and of a greater demand for soybeans, the area and production of this crop have increased during recent years.

Soutneast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA)

SEARCA is located at Los Banos, Philippines, and, in 1970, commenced uniform tests of selected varieties of high protein crops in seven locations in Southeast Asia. The objective of these tests was mainly to assemble promising varieties of soybeans and to channel new high yielding varieties to national programs in Southeast Asia, for evaluation and release for commercial production. The countries which participated in this program were the Philippines, Thailand, Malaysia, Indonesia, Laos, Khmer Republic and South Vietnam. For the first two years, SEARCA provided nominal financial support to conduct the trials. With the advent of the international programs (AVRDC, INTSOY and IITA) SEARCA decided to terminate its support of the trials. However, the program will be continued in an expanded form through its linkage with the International Rice Research Institute Cropping Systems Program.(8)

The varietal development of soybeans has received global attention through the above international programs, and the activities of these international institutions will continue to expand to meet the challenge of the world's population explosion. First priority should be given to streamlining, organizing and executing research objectives and to extending research results to farmers. An integrated strong team approach at the international level, and efficient and effective cooperation between research and extension at the national level, with the necessary support of government agencies, should result in improved soybean production and utilization.

CONCEPTS FOR FUTURE DEVELOPMENT

The soybean crop is a valuable candidate to help meet the global demand for caloric and protein foods, and the problem of future development should be looked at from both the national and international point of view. Fish meal may substitute to some extent for soybean meal as an animal feed, while palm oil may be a strong competitor with soybean oil. However, the uses of soybeans are much wider than only for soybean meal and oil. The increased world population will certainly create a greater demand for oil, protein and related products, and it is necessary to find ways and means to step up production to meet this demand.

We have to reorient our thinking in terms of varietal development, and sharpen our objectives, which must be based on the specific and immediate problems of the farmer, processor and consumer. Although there are some problems which are common to all countries, there are others which are specific to some countries or regions. Instead of diluting national efforts and draining the available meager resources by trying to do too many things at the same time, it will be advantageous for national programs to pay attention to specific, immediate problems, and to obtain all possible assistance from the existing international programs.

AVRDC, INTSOY and IITA have soybeans as one of their crops for development. What should be the responsibility of these international institutions? How well can their activities be linked with national programs? What is the role of national programs? Who should maintain the germplasm? Who will make the crosses? Where will one evaluate the segregating populations? What criteria do we use in selecting from the vast array of heterogeneous populations? The answers to these and other questions should provide the basic concepts for future varietal development in soybeans.

Germplasm is the key which will open the door for varietal development. In the past, valuable germplasm has been lost owing to poor storage and preservation. However, most countries are now interested in maintaining germplasm, as they recognize the importance of this material. Germplasm collection and its maintenance in a pure state with proper storage are a heavy responsibility. Most countries have neither the resources nor the manpower and facilities to undertake this task. In my opinion, trying to maintain a collection with inadequate facilities and resources will result not only in considerable confusion regarding the identity of the germplasm itself, but also be wasteful of valuable time and resources.

As can be seen in Table 18, germplasm is currently maintained in 19 different countries by 24 different institutions. There is a need to consolidate these collections and maintain them in four to six strategic centers to avoid genetic erosion. This germplasm should be freely available from these centers to anyone who is interested. It is vital to accumulate as much data as possible and include them in a catalogue for circulation to interested scientists, so that frequent screening for known characters can be avoided. International centers such as AVRDC, INTSOY and IITA should carry much of this responsibility. An operational classification of germplasm based on days to maturity, with reference to specific latitudes, has been worked out for North America. Similarly, a practical classification has been designed exclusively for Japan. There is now a need to classify germplasm for the tropics. AVRDC has taken the initiative in this direction and has offered a tentative proposal.(71)

International institutions should have a clear understanding of the specific problems in countries to which their research efforts are addressed. For instance, AVRDC has recognized that Thailand needs a high yielding variety with resistance to shattering, lodging and soybean rust. Earliness is a criteria, but not a must, since farmers will take a full season crop if it is risk-free and profitable. Several crosses have been made at the Chainat Agricultural Experiment Station with this objective, and the F_4 segregating generations have been screened. Individual plant selections have been made, and the seeds of these selections increased at AVRDC. In the following season, 614 different pedigrees were planted at Chiang Mai; the selection intensity was very high and varieties liable to shattering and lodging and poor performers were discarded. Of the 614 pedigrees, 83 were selected for further testing in the national program at different locations in Thailand.

The problems of one country will be different from those of another. A classic example is the major difference in photoperiod between temperate and tropical countries. Realizing the importance of this factor, AVRDC has screened thousands of accessions to identify photoperiod insensitivity, so that varieties with wide adaptability can be developed. Photoperiod insensitivity will not eliminate the need for more varieties, but will tend to enable the farmer to choose a variety with the maturity duration he desires, regardless of season or location. AVRDC and other researchers have identified photoperiod

Table 18. Glycine germplasm collections throughout the world

Institution	Country	No. collected	Remarks
Algot Holmberg and Soner AB Plant Breeding Station at Fiskeby, 605 90 Norrkoping	Sweden	1,200[12]	From East and North Asia
Asian Vegetable Research and Development Center (AVRDC), P.O. Box 42, Shanhua, Tainan, Taiwan	Taiwan	9,093[11]	World-wide collection, includes USDA collection (about 1,000 duplicates)
Atomic Energy Research Institute, P.O. Box 7, Cheong Kyang, Seoul	Korea	1,300[12]	Korean local varieties
Central Research Institute Pertanian (CRIA), Bogor	Indonesia	400[76]	Local and U.S. collection
Crop Experiment Station, Office of Rural Development, Suweon	Korea	300[12]	*Glycine* species
Department of Agriculture, Bankhen, Bangkok, 9	Thailand	1,680[54]	Japan and other countries
Ecole Nationale Superieure Agronomique, 145 Av. de Muret, Toulouse	France	500[12]	From Bulgaria, Hungary, China and U.S.A.
Department of Plant Breeding, G. B. Pant University, Pantnagar, Uttar Pradesh	India	4,000[12]	From U.S.A., U.S.S.R., India and Japan
Institute of Crop Breeding, Kirin Academy of Agriculture Sciences, Kung-chu-ling City, Kirin Province	Mainland China	– [12]	Local varieties
Institute for Crops and Pastures, Private Mail Bag 116, Pretoria	South Africa	600[12]	U.S. collection
International Institute of Agriculture, Private Mail Bag 5320, Ibadan	Nigeria	2,000[12]	East Africa, Tanzania
National Institute of Agricultural Sciences, Hiratsuka, Kanagawa Prefecture	Japan	2,928[12]	Local varieties
Northeast Agricultural College, Harbin, Heilungkiang Province	Mainland China	– [12]	Local varieties
Plant Breeding Laboratory, Iwate University, Ueda, Morioka City, Iwate Prefecture	Japan	200[12]	*Glycine* species
Plant Introduction Station, Amravati, Maharashtra	India	1,800[12]	Nepal, Sikkim, India and several other countries
Taiwan Agricultural Research Institute, Taichung, Taiwan	Taiwan	3,090[4]	U.S.A. and several other countries
U.S.R.S.L, Urbana, Illinois and Delta Branch Experiment Station, Stoneville, Mississippi 38776	U.S.A.	6,100[12]	Genetic types, varieties and species from several countries
Vavilov All Union Institute of Plant Industry, Gerzem 44, Leningrad	U.S.S.R.	2,500[12]	East and North Asia

Note: There are also collections in Australia, Brazil, Bulgaria, Hungary, Philippines and Romania.

insensitivity(9;10;11;24;66), and further investigations into the effects of different photoperiods on production are in progress at this Center.

Another example of differences between countries is shattering. In Taiwan, shattering is not a serious problem but, in Thailand, Indonesia and Africa it causes considerable concern. We cannot exert selection pressure for this trait in Taiwan; therefore, any national program which receives breeding materials from AVRDC will be properly advised to exert sufficient selection pressure to ensure elimination of materials which shatter.

Still another problem over which we have limited control is the available cultivable land which can be used for soybean production. In countries such as Taiwan, Japan and Korea, the land area is a major limiting factor. There are limits to intensive cultivation and increases in production per unit area above which we have to consider economic feasibility. Whatever efforts we use to increase yield, we are not going to satisfy the national needs of these countries to any significant extent. However, we should not use this as an excuse for not attempting to reach the optimum potential.

The engineering of a dynamic improvement program, integrating the different disciplines of breeding, pathology, entomology, physiology, chemistry, economics, etc. into a single team is essential if we wish to effectively organize a varietal development program. This type of integrated approach should result in the expeditious development of superior varieties with broader adaptation, better stability and wider utility. This type of integrated, organized research system is especially essential in international institutions, and is a necessary deviation from the departmentalised system existing in land-grant universities.

It is not sufficient to develop high yielding, adapted, disease resistant, non-lodging, non-shattering, high protein, high oil and 'better everything' varieties. 'It is totally immaterial how good the variety developed by the combined efforts of the research team might be *if it does not fit the needs of the producer and consumer*'.(74)

In a number of developing countries, there is a very poor link between research and extension. If this vital link is not adequately developed, an integrated approach in research alone means very little. This is a major national problem, which administrators should recognize and seek to overcome.

When we turn from an administrative and organizational approach to a completely scientific approach in increasing production, it is often remarked that we have reached a yield plateau; there is no further hope of increasing yields by conventional breeding techniques and we have to resort to novel, innovative and unconventional methods to break the low yield barrier.(42) Is it true that we have reached a yield plateau in soybean production, or only that we have not fully understood why we are unable to increase yields in farmers' fields? If we can get 4 t/ha in our experiments, we can expect, in theory and from practical experience, a yield of about 2 t/ha in farmers' fields. The maximum yield obtained in Japan is more than 7 t/ha, but the national average is only 1.4 t/ha (Table 4). The highest yield of soybeans obtained by farmers in U.S.A. is more than 6 t/ha, but the average yield in that country is only 1.9 t/ha. Even though considerable research has been conducted on soybeans to increase yields, there are still many questions which need to be answered if we are to break the low yield barrier. Innovative, novel techniques, such as somatic cell hybridization, wide crosses and DNA hybridization, are new vistas which require considerable time before they produce the desired results. The first cross between wheat and rye was made in 1876, and it is only now that Triticale bread is gradually becoming popular. This indicates that man can create useful species by combining species which are normally difficult to combine.

Soybeans have a yield potential of more than 7 t/ha, and there must be some bottlenecks retarding the attaining of even half of this level as average nationwide yields throughout the world. We must identify these bottlenecks before we can increase production. Suggested areas upon which attention should be concentrated are: (i) the effect of photoperiod and temperature, (ii) qualitative and quantitative assessments of photosynthetic efficiency, (iii) the role of the symbiotic relationship between *Rhizobium* and soybean genotypes, to see if we are getting the maximum possible benefit from this relationship (it is a complicated but wide open field), (iv) development of suitable selection criteria to fully augment the true genotypic potential under farm rather than experimental conditions, (v) response to nitrogen and nitrogen utilization patterns to produce a better harvest index, and (vi) appropriate management techniques to fully exploit the inherent yield potential.

International research centers and individual national programs are moving in this direction. We have sufficient variation in the world soybean collection within *G. max* and in the wild soybean *G. soja* from which we should be able to genetically reconstruct a type particularly in favor of a 'vastly improved harvest index'.

Finally, with everything provided, even with a 7-ton variety, it is not sufficient to increase the soybean area and production level, unless encouragement, incentives and stimuli are forthcoming from governments and private industry. It is also equally important that, to the farmer, the word 'soybeans' should mean a reliable, risk free, profitable return for his investment of land, capital and labor.

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