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THE MUNGBEAN

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PREFACE

This bulletin describes the agronomic, economic and nutritional aspects of the mungbean (*Vigna radiata*). It has been prepared as part of a program to study Biological Nitrogen Fixation for Food Production in the Tropics and was sponsored in part by the Office of Agriculture of the United States Agency for International Development with the guidance of Dr. Lloyd R. Frederick.

It is also part of a series of "State of the Arts" (SOTA) publications whose purpose is to supply information relevant to the tropics, serve as a guidance for developing countries in determining priorities for research and for training and planning purposes. Farmers in less developed countries need integrated packages of information on the management requirements of legumes and this bulletin contributes to the information that can lead to increased production in the major food grain legumes.

The Agricultural Experiment Station of the University of Puerto Rico, through its Department of Agronomy and Soils, makes this publication available as a technological package that may be useful to those who are helping the small farmer in less technically advanced societies. Thanks must be given to Dr. J. Morton and Dr. Roger Smith for preparing a preliminary draft. We appreciate the efforts of Dr. John M. Poehlman, who wrote the final draft.

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J. M. Poehlman

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THE MUNGBEAN

INTRODUCTION

The mungbean (*Vigna radiata* (L.) Wilczek), also called mung, moong, and greengram in India, and mungo in the Philippines, is a leguminous pulse crop, prized for its seeds, which are high in protein, easily digested, and consumed as food. In a symbiotic relationship with specific soil rhizobia, root nodules develop on mungbeans in which atmospheric nitrogen is converted to forms available to the mungbean plant.

The mungbean is native to the Northeastern India-Burma region of Asia. Its progenitor species is unknown. The closest wild relative is believed to be *Vigna radiata* var. *sublobata* (Roxb) Verdc., which may be found growing in wastelands of eastern India. The mungbean is cultivated most extensively in the India-Burma-Thailand region of southeastern Asia, but it is also grown in Iran, Pakistan, Vietnam, Peoples Republic of China, the Philippines, Republic of China, Malaysia, Indonesia, and adjacent countries and islands of south-eastern Asia and the South Pacific. In early days the mungbean was carried from Asia by Oriental emigrants, or by traders, to the Middle East, Africa, Latin and South America, and Australia. Although it never became a major commercial crop in any of these areas, commercial production is found in northwestern Peru; Oklahoma and Texas in the U.S.A.; and in local areas of Africa, Australia, the Caribbean, and the Middle East. Black gram (*Vigna mungo* (L.) Hepper), a close relative of the mungbean, is cultivated in India, Thailand, Australia, and other countries of southeastern Asia.

The mungbean is a short season crop adapted to multiple cropping systems in the drier and warmer climates of the lowland tropics and subtropics. Temperatures of 28 to 30°C are optimum for seed germination and plant growth. Flowering in mungbean is photoperiod and temperature sensitive being delayed by long photoperiods and low temperatures. The mungbean grows best on a deep loam or sandy loam soil. It is relatively drought tolerant, and is favored by dry weather during pod ripening to facilitate seed harvest. A symbiotic relationship exists between the mungbean plant and the cowpea type or cross-inoculation group of soil rhizobia. Economic yields are frequently low, resulting from low genetic yield potential of the varieties grown, disease and insect damage, unfavorable cultural practices, or a combination of these factors. Mungbean is usually given lower priority than the cereals in allocation of irrigation water or fertilizer, and cultural practices are inferior to those used with the staple cereals.

While grown principally for its high protein seeds, used as human food, the mungbean plant may be utilized as fodder for livestock, or the crop may be incorporated into the soil for soil improvement purposes. For food, the seeds are prepared by cooking, fermenting, milling, or sprouting. They are utilized in making soups, curries, bread, sweets, noodles, solids and other culinary products. Among the pulses, the mungbean is favored for children and older people due to its easy digestibility and low production of flatulence. Protein content of seeds averages around 22 to 24 percent. Mungbean protein is comparatively rich in lysine, an amino acid deficient in cereal grains, and deficient in methiomine, cystine, and cysteine, amino acids found abundantly in cereal grains. A diet combining mungbeans and cereal grains compensates for the deficiencies in protein quality found in either grain alone and provides a balanced amino acid content.

Research on mungbean was much neglected in the past, but has expanded rapidly in the past 10 to 15 years. Currently, research on mungbean is conducted extensively in India and the Philippines and at the Asian Vegetable Research and Development Center (AVRDC) in Taiwan. An International Mungbean Nursery started in 1972 at the University of Missouri, Columbia, has, since 1976, been distributed and coordinated through AVRDC. The First International Mungbean Symposium, during which current research results on mungbean were presented, was held at Los Baños, Philippines, in 1977. Nitrogen fixation is being studied at the University of Hawaii, Nitrogen Fixation of Tropical Agricultural Legumes (NifTAL) project. The mungbean is used extensively in biochemical studies of enzymes, hormones, growth regulators, and various plant metabolic processes. There has been no major production research breakthrough with mungbean such as occurred with the dwarf cereals. Yield increases in the future will most probably come through a combination of small advances in several production inputs. Increased extension efforts must go hand in hand with the advances from research if farmers are to benefit from the new technology.

II ECONOMIC IMPORTANCE

The mungbean is a leguminous species, or pulse crop, grown principally for its edible seeds. The pulse crops, in addition to mungbeans, include several species of legumes with edible seeds, such as garden and dry beans (*Phaseolus vulgaris* L.), lima or butterbeans (*P. lunatus* L.), broad bean (*Vicia faba* L.), garden pea (*Pisum sativum* L.), chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medik.), pigeon pea (*Cajanus cajan* (L.) Huth), cowpea (*Vigna unguiculata* (L.) Walp.), blackgram (*Vigna mungo* Hepper), adzuki bean (*Vigna angularis* (Willd.) Ohwi and Ohashi), and others of lesser importance. Mungbeans and other pulses are also referred to as grain legumes, although the latter ter usually encompasses a wider range of species, including soybeans (*Glycine max* (L.) Merr.) and peanuts (*Arachis hypogaea* L.), which are grown principally as oilseed crops.

The pulse crops have traditionally provided an economical source of vegetable protein food. The largest production and consumption of the pulses occur in those countries or regions where the economy does not support large scale production of animal protein, or with those people who prefer a vegetable protein in their diet for cultural or economic reasons. Because pulses supply a cheaper source of protein than animal products, about 80% of the pulse production is in the developing countries. But the current high market price of mungbean in the Philippines and other Southeast Asian countries is changing the image of mungbean as the "poor man's" meat.

World Production

There are no official statistics on the world production of mungbeans. According to the "FAO Production Yearbook for 1978," (Food and Agriculture Organization, 1979) the world total area planted to pulses is 82.9 million hectares (ha) with production of 62 million metric tons (m.t.). In the FAO compilation of statistics, mungbean production is included under "dry beans." In 1978, the area planted to dry beans was 29.6 million ha with production of 17.2 million m.t. The FAO dry bean classification includes "*Phaseolus vulgaris*, *P. lunatus*, *P. radiata*, *P. mungo*, and *P. angularis*." (The three latter species are currently classified in the genus *Vigna*.) The proportion of the area planted to dry beans that is occupied by mungbean is not reported. Soybean and peanuts are not included in the FAO pulse production statistics. Mungbeans are often planted after cereals for home consumption, or grown as garden crops, and some of the acreage or production for these purposes may have been omitted in compiling official FAO statistics.

Information collected from various sources on mungbean production in the most important mungbean producing countries, is summarized in Table 1. From the data available, world mungbean production is estimated to be around 1.2 million m.t., harvested from 3.0 million ha. This production of mungbean

Table 1. Mungbean Production in Selected Countries.

Country	Year[a]	Area	Seed Yield	Production	Source
		ha	kg/ha	m.t.	
Australia	1978-79	5,922[b]	380	2,250[b]	Lawn (personal correspondence, 1980)
Bangladesh	1970-75	15,204	663	10,081	Islam (1978)
Burma	1975	108,540	439	47,676	Haq (1977)
India	1977	1,940,000	309	600,000	Tiwari (1978)
Indonesia	1976	147,449	468	68,971	Somaatmadja and Sutarman (1978)
Iran	1977	27,500	550	15,129	Amirshahi (1978)
Japan		100	100	1,000	Konno and Narikawa (1978)
Kenya	1979	9,934	450	4,470	Waite (personal correspondence, 1980)
Korea	1979	6,212	891	5,524	Hong (personal correspondence, 1980)
Malaysia, West	1973	70	450	32	Abubakar, Haron, and Aziz (1978)
Pakistan	1974-75	70,000	429	30,000	Khan and Shakoor (1977)
Philippines	1975	39,320	550	21,617	Catedral and Lantican (1978)
Sri Lanka	1976	8,340	544	4,540	Vignarajah (1978)
Taiwan	1975	4,300	660	2,840	Calkins (1978)
Thailand	1977-78	435,153[b]	474	206,131[b]	Nalampang (personal correspondence, 1980)
U.S.A.	1974	1,835			Oklahoma, 1974 Census of Agriculture
Vietnam (South)	1967	30,560	650	19,920	Thuy (1969)

[a] The latest year for which production figures are available is used.

[b] Includes mungbeans and blackgram.

would be about 2% of the world production of pulses, 7% of the production of all dry beans, 18% of the production of chickpea, and about equal to the production of cowpea or lentil.

The major mungbean production area is southern and southeastern Asia, from Iran eastward through Pakistan, India, Bangladesh, Burma, Thailand, Philippines, and Indonesia. Four countries in this arc--India, Burma, Thailand, and Indonesia--produce almost 90% of the recorded world production. Estimates are not available on production in China, U.S.S.R., several countries of southeast Asia and adjacent Pacific Islands, the Middle East, Russia, Central and South America, or Africa except for Kenya. Outside of Asia mungbeans are exported from Peru, Kenya, and other east African countries. They are frequently found in local markets in African and Caribbean countries where oriental people are living. They may be grown, also, as garden crops in many of these countries.

Production by Countries or Regions

Australia: Mungbean is grown in areas of marginal summer rainfall in New South Wales and Queensland (Lawn, 1978). It is a minor crop, only 300 ha were planted in 1971-72, but the total area planted to mungbean and blackgram increased to 15,350 ha in 1977-78. The increase resulted from a search for alternative crops to diversify Australian agriculture, the high world demand for high protein food and feedstuffs, and the economy of growing a crop which does not require nitrogen fertilizer (Bott and Kingston, 1976; Lawn and Russell, 1978). In 1978-79, planting was hindered by deficient rainfall and prices were lower, so the area planted dropped to 5,922 ha (Lawn, personal communication). Blackgram produces higher yields than mungbean in Australia.

Bangladesh: The pulses rank third after rice and jute in area planted. Mungbean accounts for only 5% of the pulse acreage and blackgram occupies 16% (Islam, 1978). Although favored for its quality, acreage of mungbean is limited by its susceptibility to water-logging. It is generally planted after paddy rice.

Burma: Burma is the fourth ranking country in production of mungbean with 108.5 thousand ha (Haq, 1977). Among the pulses grown in Burma, mungbean ranks third, after chickpea and lima bean, occupying 14% of the area planted. Blackgram is planted on 29 thousand ha. Both mungbean and blackgram are grown after rice, often being broadcast before the rice is harvested. Mungbean is grown both for domestic use and export.

India: India is the world's leading country in production with 1.9 million ha (Tiwari, 1978). In India, mungbean ranks third among the pulse crops, after chickpea and pipeonpea (C. Singh and Yadav, 1978). Mungbean is cultivated in all of the states of India, but largest production is in Orissa, Maharashtra, and Andhra Pradesh (H. B. Singh, Joshi, and Thomas, 1970). Due to the diversity in local environments, the crop may be grown in any month of the year in one area or another. The major production comes from mungbean planted after rice and grown on residual moisture after the rice harvest.

Multiple cropping with mungbean during the summer season (March to May) is increasing as new early maturing varieties are developed and more irrigation water becomes available. The crop is grown principally for domestic use.

Indonesia: Mungbean production increased 60% between 1969 and 1976, and it now ranks third among the grain legumes grown in Indonesia (Somaatmadja and Sutarman, 1978). As a country Indonesia ranks third in production. Mungbean is grown for domestic use, much of it being consumed in the form of "porridge."

Iran: Mungbean ranks fifth among the food legumes in Iran, with an estimated area of 25 to 30 thousand ha in production (Amirshahi, 1978). Mungbean is cultivated on the Central Plateau, and in the southeastern and southwestern areas of Iran. Mungbean is grown in small fields for domestic use, particularly among low income people, who eat it with vegetables and rice.

Japan: Production is insignificant despite a strong market demand. Use is dependent upon imports from Thailand and Burma, which are consumed mostly as bean sprouts (Konno and Narikawa, 1978). Blackgram is preferred to mungbean for bean sprouts in Japan.

Kenya: Mungbeans are produced for domestic use and export (Acland, 1971). Estimates of area planted and production were obtained through provincial officers in four provinces where mungbean production is most important. Kenya is an important source of U.S. imports.

Korea: Mungbean is a minor crop in Korea, the area planted being only 2.5% of that planted to soybeans. Mungbeans usually follow barley or wheat in the cropping system.

Malaysia: Although mungbean is generally available in local markets, traditionally they have been imported, and production is negligible in both West- and East Malaysia (Abubaker, Haron, and Aziz, 1978; Tsiung, 1978).

Middle East: There are no available estimates on mungbean production in the Middle East, although mungbean is grown in Iraq and other countries for domestic use, and records show importation by the U.S.A. from Turkey.

Pakistan: Mungbean ranks third among pulse crops in Pakistan after chickpea and pea, but occupies only 5% of the total area planted to pulses, compared to 75% for chickpeas (Khan and Shakoor, 1977). Mungbean is usually grown as a summer crop (February to June), but may be grown as a rainy season crop (July to November). The production is for domestic use.

Peru: Mungbean is a commercial crop in the Northwest Coastal area. No production statistics are available. Peru is a major source of U.S. imports.

Philippines: Mungbean is a favored pulse crop in the Philippines. Production has been relatively constant in recent years, but is insufficient to meet domestic needs (Palo, 1974; Calkins, 1978). It is usually planted as a dry land crop following rice.

Sri Lanka: Mungbean is the preferred legume in the national diet but it has taken second place in cultivation to cowpea due to diseases and low yield (Vignarajah, 1978). Market demand is not met by local production (Fernando, 1974). Efforts are being made to increase domestic production and reduce imports. Blackgram has increased in production, along with cowpea.

Taiwan: Mungbean is a minor crop in Taiwan, but demand is high with 80% of the consumption being met by imports (Park, 1977; Calkins, 1978). The mungbean is grown in an intensive multiple cropping system, usually in spring (March to May) before rice. Mungbean is a poor competitor with other crops due to the instability of yields.

Thailand: Thailand ranks second in production of mungbean after India. Mungbean is the major pulse crop in Thailand. The area planted increased from 37 to 435 thousand hectares between 1961 and 1977-78 (Nalampang, 1974; 1978). Over 66% of the mungbeans are produced in four provinces in the Northern and Central Regions (Bhumiratana, 1978). Current reports combine mungbean and blackgram in production statistics. About one-third of the production is exported, making Thailand the major exporter of mungbean and blackgram. The crop is grown in three seasons: (*a*) early season (April to May) with first monsoon rains, (*b*) end of rainy season (September to October) after corn in upland areas, and (*c*) after rice (January to February) in lowland areas. About two-thirds of the production is from the September-October plantings.

U.S.A.: Production is in the states of Oklahoma and Texas. The Oklahoma Crop and Livestock Reporting Service has discontinued making estimates of production, but the 1974 Census of Agriculture lists 1,835 ha harvested in Oklahoma in that year. The quantity produced is not reported.

Vietnam: Information is available only from South Vietnam before reunification. There, mungbean was the major pulse crop with cultivation principally in the Southern Lowland Region, with lesser production in the Central Lowlands and the Central Highlands (Thuy, 1969).

Other: Although seldom reported, mungbean is grown in several areas of Africa. Exports to the U.S.A. in recent years have been received from Kenya, Malawi, South Africa, and other countries. The mungbean was probably introduced to Africa by Oriental immigrants. In the Carribean area, mungbeans are sometimes grown as garden crops.

Production for Local Markets and Export

Most mungbeans produced in Southeast Asia are produced for home consumption or for local markets. Because yields are generally low and unstable, fluctuating widely from season to season with fluctuations in the moisture supply and other production factors, market supply and price also vary. While price may receive only minor consideration in deciding size of plantings for home consumption, it is important in determining the amount of commercial production and the production inputs that will be expended in efforts to obtain higher yields. Expansion of the mungbean crop in Australia from 1735 ha in 1974-75 to 15,350 ha in 1977-78 was checked in 1979 by low yields due to low summer rainfall and by low prices.

Thailand is the major mungbean exporting country in Southeast Asia. Although second to India in production, domestic consumption is much smaller. Exports in 1976 were 49,800 m.t. of mungbean and 30,600 m.t. of blackgram (Nalampang, 1978). Most of the mungbean exports go to Japan, Taiwan, Philippines, Malaysia, and Singapore, but significant quantities go to Europe and North America in addition. Blackgram exports go almost entirely to Japan. Due to the strong foreign market demand, the farm price in Thailand for mungbean increased from $177 (U.S.)/m.t. in 1975 to $352 in 1976. With the higher farm price, the area planted to mungbean and blackgram in Thailand nearly doubled from 1976-77 to 1977-78. Export prices remained high, being $350 to $400 (U.S.)/m.t. for mungbean, and $450 (U.S.)/m.t. for blackgram (Nalampang, personal correspondence, 1980).

About 75% of the mungbeans used in the U.S.A. are imported. The originating country and the quantity of imports for the years 1977-78 and 1978-79 are listed in Table 2. Major imports were received from Australia, Peru, Kenya, and Thailand. The cost of the mungbeans imported averaged $671/m.t. in 1978 and $587 in 1979 (U.S.D.A., Foreign Agricultural Service, personal correspondence).

Table 2. Imports of Mungbean into the United States.

Country of Origin	Quantity Imported[a] 1977-78	Quantity Imported[a] 1978-79
	m.t.	m.t.
Australia	36	688
China, Peoples Republic	41	12
Hong Kong	22	3
India	66	5
Kenya	279	310
Malawi	41	3
Peru	310	361
Sri Lanka	0	10
South Africa, Republic of	0	6
Taiwan	1	19
Thailand	202	236
Turkey	0	10
Other	15	65
Total	1013	1728

[a]United States Department of Agriculture, Foreign Agricultural Service.

Economics of Mungbean Production

Mungbean is widely perceived to be a low production-low income crop. This viewpoint affects production procedures. The low production syndrome results from several factors: (*a*) low genetic potential in native varieties, (*b*) yield fluctuations due to drought and floods, (*c*) losses from disease and insect pests, and (*d*) poor cultural practices. Because yields fluctuate widely, cultural procedures requiring even moderate investments of labor or capital are practiced infrequently, thus contributing to the vulnerability of mungbean to succumb to unfavorable natural hazards. Throughout much of Southeast Asia, mungbean is usually planted at the end of the monsoon season, following the harvest of paddy rice, and left to grow on soil largely exhausted of its fertility and moisture. Only minor control of weeds, diseases, or insects is normally practiced.

A study was made of the economics of Asian mungbean production in Thailand, the Philippines, and Taiwan (Calkins, 1978). The comparative production costs per hectare for the three areas are given in Table 3.

Table 3. Comparative Costs of Mungbean Production in Three Asian Countries.[a]

	Thailand	Philippines	Taiwan
Number of case studies	108	161	73
Average field size, ha	2.14	0.79	(0.2)
Yield of mungbean, kg/ha	268	334	800
Production cost (U.S. dollars/ha)	$37.7	$191.6	$435.5
Income (U.S. dollars/ha)	$40.2	$154.0	$453.7
Net return (income less cash expenditures, in U.S. dollars/ha)	$34.1	$43.1	$109.1
Labor (hrs/ha)	200.1	318.3	651.0
Proportion of production cost charged to:			
Labor	58%	29%	66%
Materials (seed, fertilizer, etc.)	22%	24%	13%
Capital (interest, taxes)	20%	47%	21%

[a]Adapted from Calkins (1978).

Climatic conditions were similar for the three areas. In Thailand, mungbean in the area studied is grown in two seasons, one beginning in April with the early rains, and one in August with the monsoon rains. Field size is comparatively large and labor requirement per hectare is low, compared to the other locations. Yield is low due to a low level of production inputs. In Taiwan, most mungbean is grown during the hot-dry season (March to May) ahead of the monsoon rains. The crop requires irrigation and has a high labor requirement. Yield is high due to the intensive production inputs. In the area of the Philippines where this study was made, mungbean is generally planted in December after lowland rice. Field size, labor requirement, and yield were intermediate to the Thailand and Taiwan locations. The net return from mungbean (gross income less cash expenditures) was lowest in Thailand, where yields were lowest, and highest in Taiwan where yields were highest.

The major production expense in Thailand and Taiwan was for labor, requiring 58% and 66%, respectively, of the total expenditures. Of the labor costs, harvesting was the most expensive single operation. Although both the amount of labor required to grow the crop and the wage rates were higher in Taiwan, they were offset by a higher yield. Labor costs were proportionately lower in the Philippines, but this was offset by higher capital expenditure. The cost of seed and fertilizer was similar at the three locations. The study suggests that improvement of production practices in Thailand to obtain higher yields would increase returns, if labor costs can be maintained at the low level reported in the study. It is of interest that the net return per hour of labor worked is higher in Thailand than in Taiwan. In the Philippines, where mungbean is grown under conditions comparable to the case studies reported, improvement in technology to increase yield and reduction in cost of capital would provide higher returns. In Taiwan, due to the small farm size, high returns per unit of land is more important than high return per unit of labor, hence a high production technology is essential.

In Thailand, the Philippines, and Taiwan, where the above study was made, fields are small and production practices are not highly mechanized. In Oklahoma, U.S.A., mungbean is grown with highly mechanized cultural practices, including combine harvesting. In an economic analysis of mungbean production in Oklahoma, the cost and returns for growing mungbean in a double cropping system with wheat was compared with growing wheat alone (Tomlinson and Plaxico, 1962). For the period studied, the return for land, labor, and management was essentially double for a combined crop of wheat and mungbean as for growing wheat alone. The production of mungbean provided a return from the land additional to that obtained from growing only wheat. Additional costs included labor, machine operation, and seed for growing the mungbean. No additional machinery was needed since mungbean is planted and harvested with the same machinery used for wheat. No alternative use for the land was considered if mungbean was not planted. Currently mungbean competes with soybeans, a high income crop, for a place in the rotation.

An important need in all production areas is to find a production technology that will give more stable yields and reduce risks associated with the erratic production of mungbean. This will require breeding of improved varieties, tillage practices to obtain uniform stands, cultural practices to reduce losses from drought, improved fertility programs, utilization of efficient strains of rhizobia, and reduction of loss from diseases and insects. Uniform maturity to reduce the labor requirement for harvesting would make mungbean a more profitable crop to grow. Another need is the development of an efficient market system to handle mungbean grown in quantities above that needed for local home consumption. The losses incurred in farm storage often impel farmers to sell at harvest time at reduced prices.

III HISTORY, CLASSIFICATION, AND DESCRIPTION

History

The mungbean is native to the India-Burma area of Southeast Asia and was included by Vavilov in his Indian and Central Asiatic centers of origin of cultivated crop plants (Vavilov, 1951). Production in ancient times has been verified by discovery of carbonized grains in a Chalcolithic site in Madhya Pradesh state of India, which were dated 1660 to 1440 B.C. (Vishnu-Mittre, 1974). But mungbean was not the earliest pulse crop in cultivation having been preceded by peas, lentils, lathyrus, chickpea, and others. De Candole (1886) pointed to the use of several vernacular names for mungbean in India as evidence of cultivation for one- to two-thousand years. Mungbean has not been found growing wild (Žukovskij, 1950), yet it has been cultivated in all states of India, Burma, Ceylon, Iran, China, and eastern regions of the Soviet Union since early times. From Asia, mungbean was carried by early Oriental immigrants or traders into the Middle East, the Pacific Islands, Australia, East Africa, and the Americas. Outside of Asia, there has been only limited cultivation as a commercial or garden crop. Mungbean was introduced into the U.S.A. during the latter part of the nineteenth century, but commercial production was not started until during World War II when trade was cut off from Asian countries.

Classification

The mungbean is classified in the Order Leguminosae, Family Papilionoideae. The botanical name currently recognized for mungbean is *Vigna radiata* (L.) Wilczek, and for blackgram, a close relative, *Vigna mungo* (L.) Hepper (Verdcourt, 1970). Nomenclature of the species has been confusing. The names *Phaseolus radiatus* L. and *P. aureus* Roxb. have been used extensively for mungbean and *P. mungo* L. for blackgram. In recent years taxonomists reexamined the distinction between the genera *Phaseolus* L. and *Vigna* Savi which was based on the degree that the beak of the keel was incurved. New evidence suggested that certain old world species placed in *Phaseolus* by this criterion were more closely related to species of *Vigna* than to the new world species of *Phaseolus*. This led to a change in the taxon of mungbean, blackgram and other related Asiatic species formerly classified in *Phaseolus* L. to *Vigna* Savi (Verdcourt, 1970). The change has been supported by pollen grain studies (Taylor, 1966), electrophoresis studies on seed proteins (Sahai and Rana, 1977), and serological evidence (Kloz, 1971; Chrispeels and Baumgartner, 1978).

While accepting the taxon of Wilczek for mungbean and Hepper for blackgram, Verdcourt (1970) recommended three subspecies designations for *Vigna radiata* as follows:

Vigna radiata (L.) Wilczek
var. *radiata* (for mungbean)
var. *sublobata* (Roxb.) Verdc. (formerly *Phaseolus sublobatus* Roxb., *P. trinervius* Wight and Arn.)
var. *glabra* (Roxb.) Verdc. (formerly *P. glaber* Roxb.)

The change in taxon of mungbean and related species from *Phaseolus* to *Vigna* has been adopted by the United States Department of Agriculture (Gunn, 1973).

Both mungbean and blackgram have many common names, (Chatterjee and Randhawa, 1952; International Seed Testing Association, 1968). For mungbean these include mung, moong, mongo, mungo, and greengram; for blackgram, urd, urid, mash, and mungo. Mungbean and blackgram, are often referred to as the Asian grams.

Description of Mungbean (*Vigna radiata* (L.) Wilczek)

The mungbean is an annual, semi-erect to erect or sometimes twining deep-rooted herb, 25 to 100 cm tall (Hooker, 1879; Prain, 1903; Piper and Morse, 1914; Ochse and van den Brink, 1931; Backer and van den Brink, 1963; Purseglove, 1974; Brouk, 1975). The stems are branching from the base and covered with short fine brownish hairs. The leaves are alternate and trifoliate, or sometimes with five leaflets. Leaflets are medium to dark green, broadly ovate, sometimes lobed, rounded at the base and pointed at the apex, 5 to 12 cm long, and 2 to 10 cm wide. From 10 to 25 flowers are borne in axillary clusters or racemes. The flowers are greenish to bright yellow, with a grey tinged keel, 1 to 1.75 cm in diameter. The seed pods, which radiate horizontally in whorls, are cylindrical, straight to strongly curved, and pointed at the tip. When mature, the pods are glabrous or have short hairs, tawny brown to black, 5 to 14 cm long, and 4 to 6 mm wide. Seeds, borne 8 to 20 per pod, are nearly round to oblong; glossy or dull; with green, yellow, tawny brown, black, or mottled testae. Dull seeds are coated with a layer of the pod inner membrane which may be translucid or pigmented (Watt, Poehlman, and Cumbie, 1977). If translucid, the seed color is determined by the color of the testa underneath. The testa is reticulated with numerous fine wavy ridges and cross walls (Bose, 1932A; Watt and Marechal, 1977). Seeds weigh 15 to 85 mg, averaging 25 to 30,000 seeds per kg. The hilum is round, flat, and white. Pods may burst open when dry, shattering the seeds. Seed germination is epigeal. Flowers are self-fertile and highly self-pollinated. Flowering is indeterminate and continues over a period of several weeks if the plant stays healthy. Pods mature about 20 days after flowering. Rapid senescence does not occur.

Description of Blackgram (*Vigna mungo* (L.) Hepper)

The blackgram is an annual, semi-erect to spreading herb, 25 to 90 cm tall (Piper and Morse, 1914; Bose, 1932B; Purseglove, 1974). Stems are diffuse, branching, sometimes procumbent, and covered with long, dense, brown hairs. Leaves are trifoliate, hairy, with large ovate to laceolate, entire, leaflets. Flowers are pale yellow, 12 to 15 mm in width, with a yellow spirally coiled keel. The flowers are borne in clusters of 5 to 6 on a short hairy peduncle, in axillary racemes. Pods are short, erect to suberect, brown, hairy, with 6 to 10 seeds. Seeds are small, averaging about 40 mg; oblong; black, dark brown, or green. The testa is smooth and the hilum white and concave. Germination is epigeal. Pods do not shatter readily. Flowers are self-fertile and self-pollinated. Flowering is indeterminate.

Differences Between Mungbean and Blackgram

The taxonomic distinction between the Asian grams, mungbean and blackgram, is still being studied. In Asia where the mungbean and blackgram has been grown most extensively, they have long been considered to be separate species. But some taxonomists have questioned the distinctiveness of the two groups. Verdcourt (1970) noted that they are "scarcely more than variants of the same species." Rachie and Roberts (1974) in discussing the grain legumes of the lowland tropics considered mungbean and blackgram to be subspecies of *Vigna radiata*, var. *aureus* for mungbean, and var. *mungo* for blackgram. Combining these taxons does not receive support from most researchers working with the Asian grams.

Morphological distinctions between mungbean and blackgram were given in the above descriptions. In addition to morphological evidence supporting separate species, differences have been reported from phytochemical and genetic studies. The chemotaxonomic distinction is based on seeds of *V. radiata* and the wild subspecies, *V. radiata* var. *sublobata*, containing a free dipeptide, γ-glutamyl-S-methylcysteine, which in *V. mungo* is replaced by γ-glutamylmethionine (Otoul et al., 1975). In cytogenetic studies of the two species, Dana (1966A) reports that the two species have a common genome designation, but the F_1 plants of crosses between the species have a high proportion of sterility, suggesting the presence of a partial incompatibility barrier separating the two species. Bhatnager et al. (1974) report mungbean to have four pairs long and seven pairs medium-length chromosomes, and blackgram to have one pair long, six pairs medium, and four pairs short chromosomes. Mungbean and blackgram are partially cross-fertile when mungbean is used as the female parent.

In this publication mungbean and blackgram will be treated as separate species. References to and comparisons between the species will be made frequently since cultural practices and utilization are similar, and the two species are competitive for a place in the cropping system and in the market place.

IV CLIMATIC REQUIREMENTS

The mungbean is grown mainly in semiarid to subhumid lowland tropics and subtropics with 600 to 900 mm annual rainfall and not exceeding 2,000 m elevation. Major climatic factors affecting adaptation of mungbean are photoperiod, temperature, precipitation, and solar radiation. Conditions such as windstorms and hail can be locally destructive. High humidity may foster development of foliage diseases. Although the influences of climatic factors are considered separately in the following discussion, they do not act in isolation. Their effects interact to produce the climate characteristic of a particular geographic area and the microclimates present within the area.

Photoperiod

The mungbean is a short day plant, flower initiation being delayed by increases in the length of the photoperiod (Allard and Zaumeyer, 1944; Sen Gupta and Mukherji, 1949; Bashandi and Poehlman, 1974; Aggarwal and Poehlman, 1977; Rawson and Craven, 1979). The photoperiod response restricts the latitude at which mungbean may be grown and the adaptation of varieties at particular latitudes. As mungbean is moved north, or south, from the equator, flower initiation is delayed. At latitudes above 40 to 45 degrees, flowering occurs late in the season, with fruiting further delayed by low night temperatures, so that the crop may not ripen before frost.

Mungbean strains differ in response to photoperiod. While all genotypes will usually flower in photoperiods of 12 to 13 hours, flowering is progressively delayed as the photoperiod is extended. The amount of delay will be affected by (*a*) the length of the photoperiod, and (*b*) the genetic response of the mungbean strain. As the photoperiod is lengthened from 12 to 16 hours, flowering in some short-season, early strains may be delayed only a few days, but photoperiod sensitive strains may be delayed as much as 30 to 40 days. In long photoperiods some strains may even fail to flower (Bashandi and Poehlman, 1974). Generally, a higher mean temperature will hasten flowering, or a lower mean temperature will delay flowering, at all photoperiods, but this relationship does not hold for all strains of mungbean (Aggarwal and Poehlman, 1977; Rawson and Craven, 1979).

At the Asian Vegetable Research and Development Center (AVRDC) in Taiwan, 1,273 mungbean accessions were screened for their photoperiod response by comparing the days-to-flowering in 12- and 16-hour days. Screening was done by planting the accessions in the field in March prior to the vernal equinox and comparing one planting exposed to natural daylength, which averaged about 12 hours, with a second planting given four hours of supplemental lighting to increase the photoperiod to 16 hours (MacKenzie et al., 1975). Flowering in the two treatments differed by 10 days or less in 47% of the accessions indicating that they were relatively insensitive to photoperiod. In 18% of the accessions, flowering in the longer photoperiod was delayed by more than 10 days, indicating moderate photoperiod sensitivity. Thirty-two percent did not flower at 16 hours indicating extreme photoperiod sensitivity. Four percent did not flower at either 12 or 16 hours for an unknown reason. Strains with low photoperiod sensitivity are desired where mungbean is planted as a short duration crop in a multiple cropping rotation, or for planting in different seasons. When grown as a long duration crop, strains with low photoperiod sensitivity may mature too early for production of maximum yield. At higher latitudes, photoperiod sensitive strains may flower too late to ripen a full harvest within the growing season, or may even fail to flower before frost occurs.

Temperature

Mungbean is a warm season crop, and will grow within a mean temperature range of about 20 to 40°C. It is sensitive to low temperatures and is killed by frost. Carefully documented information on the minimum/optimum/maximum temperatures for mungbean growth is scarce. From observations of the International Mungbean Nurseries, Poehlman (1978) suggested that mean temperatures of 20 to 22°C may be the minimum for productive growth, with mean temperatures in the range of 28 to 30°C being optimum.

Mungbean is adversely affected by low temperatures being subject to both chilling and frost injury. Aggarwal and Poehlman (1977) noted that mungbean plants grown in an 18°C mean temperature were stunted, developed lesions, and were generally unthrifty or even died. The critical temperature of a plant species is the temperature below which growth ceases and the plant eventually dies. In mungbean, the critical temperature, as measured by changes in the structure and function of cellular membranes, is about 15°C (Raison and Chapman, 1976). Below 15°C, a thermal transition occurs in the membrane lipids of mitochondria and chloroplasts. Another thermal transition occurs just below 28°C which suggests that this may be the optimum temperature for growth. With temperatures above 28°C, increases in transpiration and respiration could offset benefits from increases in photosynthesis and retard plant growth. In a phytotron experiment with mungbean, Rawson and Craven (1979) reported that low photoperiod sensitive strains produced highest yields at 24°C and that photoperiod sensitive strains produced highest yields at 27°C. Yields dropped off sharply at 30°C and 33°C mean temperatures. So far, there is little information on the effects of the diurnal range of temperature, or the effect of cool night temperatures, on growth of mungbean.

Warm temperature is essential for rapid germination of mungbean seeds. Studies at AVRDC indicate optimum temperature for germination to be 29 to 31°C (Park, personal communication). Germination is inhibited by low temperature. In a germination study, the rate of germination declined slowly below 25°C, dropped off sharply below 14°C, and virtually ceased below 11.5°C (Simon et al., 1976). At 10°C, only 2% of the seed germinated after a week and only 5% after three weeks. Failure of the seeds to germinate appeared to be due to low temperature inhibition of mitosis since root elongation did not occur. In climates where the growing season is limited by the length of the frost free period, mungbean should not be planted in the spring until the soil and air temperatures have warmed up to around 25°C or above.

Temperature affects the length of the vegetative growth phase and the initiation of flowering. Increasing the mean temperature during the vegetative phase hastens flowering (Aggarawal and Poehlman, 1977; Rawson and Craven, 1979). But flower shedding is increased also by temperature, particularly if moisture is deficient.

Dry mungbean seeds tolerated exposure for one hour at temperatures up to 70°C without affecting seedling growth, but seedling growth was retarded if exposure of the seed exceeded 70°C (Vora and Patel, 1975). This is of interest since mungbean seed is often planted in summer, when the surface soil reaches extremely high temperatures. Exposure of seeds to 40 and 50°C for 1 to 3 weeks caused the development of cracks in the raphe, thereby reducing the number of hard seeds and increasing germination (Manohar, Misra, and Mathur, 1969).

Precipitation and Soil Moisture Stress

Mungbeans are generally unsuited in the wet tropics where annual precipitation is above 1,000 mm (Jain and Mehra, 1980). Mungbean plants are readily damaged by heavy rain, and by windstorms. High humidity during the growing season increases incidence of foliar diseases. Prolonged rainy periods during pod ripening may result in molding of the seeds, or even sprouting of the seeds in the pod as mungbean does not possess seed dormancy. Mungbean does not tolerate waterlogged conditions and is inferior to blackgram in this respect (PCARR, 1977), but reasons for the difference have not been explained. At AVRDC, mungbean was found inferior to soybean and winged bean in flood tolerance (Park, personal communication). Varma and Rao (1975) reported seed yields, nodule dry weight, and N content of mungbean plants in a pot experiment to be reduced at high moisture levels.

Mungbean is reputed to be a drought tolerant crop and is grown frequently under dryland conditions where soil moisture is limited. In Southeast Asia, mungbean is commonly planted at the end of the rainy season following harvest of lowland rice, and where it grows on residual soil moisture only. But it is also grown during the rainy season (July to September), or during the hot, dry summer season (March to May) ahead of the monsoon rains if irrigation water is available. For high seed quality, mungbean should ripen during a bright, rainfree period.

Soil drought stress in pot experiments reduces vegetative growth and the initiation and retention of floral buds (Ali and Alam, 1973), and seed yield (Varma and Rao, 1975). Experiments on time of irrigation emphasize the importance of avoiding drought stress immediately before and during the flowering period if optimum yields are to be obtained (Jana, Das, and Sen, 1975; A. Singh and Bhardwaj, 1975; Agarwal, Behl, and Moolani, 1976; and Chiang and Hubbell, 1978). While these experiments report the adverse effects of soil stress, and the growth stages at which irrigation water should be applied to avoid drought stress, they do not provide critical data from which the relative drought tolerance of mungbean can be compared with other grain legume crops, such as cowpea or soybean. Some information about the latter is provided by an experiment in Australia, in which strains of mungbean and cowpea were compared under two environments, one with favorable moisture throughout the season, the other with drought stress during the fruiting period (Mungomery, Byth, and Williams, 1972). The mungbean strains were better able to withstand the drought stress, but were less responsive than the cowpea strains in the favorable moisture environment.

Some experimental results suggest that mungbean may not have the drought tolerance it is reputed to have. In Taiwan the water requirement of mungbean was 3.2 mm/day, which equalled the water requirement of corn and soybeans, and exceeded a 2.8 mm/day requirement of sorghum (National Taiwan University, reported by Chiang and Hubbell, 1978). In the Philippines the daily water requirement is reported to be 4 to 5 mm/day depending on the temperature, solar radiation and evapo-transpiration rate (PCARR, 1977). No comparisons are reported with other grain legumes in either study.

The effect of drought stress on net photosynthesis of mungbean was measured at AVRDC (AVRDC, 1978A). When leaf water potential was below -2 bars, net photosynthetic rate was reduced, indicating extreme sensitivity to water stress. Soybean and tomato were comparatively less sensitive. The apparent tolerance to drought of mungbean grown on residual moisture after lowland rice may be due to drought avoidance rather than to its ability to endure greater drought stress; the short growing season for the mungbean plant enabling it to reach maturity before residual soil moisture is completely exhausted. Because mungbean is often grown after rice on a declining soil moisture supply, information is needed on the ability of field grown mungbean plants to adapt to increasing shortages of soil water as the season progresses.

Drought stress during flowering may increase the production of hard seeds (Ishii, 1968, and 1969). Drought stress in combination with high temperature increases flower shedding and reduces seed set.

Solar Radiation and Photosynthesis

Mungbean is grown both in summer seasons when there is an abundance of sunshine and in rainy seasons when the solar radiation is diminished by cloud cover. Yet, the requirements for solar radiation in mungbean has not received much study. In Taiwan, mungbean yields increased with increases in solar radiation during the 30 days following seedling emergence (AVRDC, 1979). Clifford (1979) obtained a twofold increase in yield of mungbean by growing in 'bright' light (150 W/m^2) rather than 'dim' light (50 W/m^2).

Solar radiation supplies the energy utilized in photosynthesis. The mungbean is a C_3-type plant with respect to photosynthetic activity. Seed yield is an end product of (*a*) photosynthesis (source), (*b*) translocation, and (*c*) storage of assimilates (sink). The amount of photosynthesis is a function of the total leaf area and the solar radiation intercepted. In a study of fruit and seed development in mungbean, fruiting began at the fourth node, was highest in the fifth node, and then decreased from the fifth node upward to the eighth node (Savithri, Ganapathy, and Sinha, 1978). Seed weight at the different nodes was correlated with the leaf area at that node ($\underline{r} = 0.85$), indicating that a large leaf area which intercepts maximum light is needed to obtain high yields.

Translocation experiments with ^{14}C labeled assimilates show that carbon assimilated during the vegetative phase of growth is not used in seed development, the seed requirement being met from carbon assimilated after anthesis (Kuo, Jung, and Tsou, 1978). Similar conclusions were reached from a defoliation experiment in which removal of leaves from young mungbean plants reduced development of stems and leaves, and defoliation during the reproductive stage reduced seed yield (Enyi, 1975). In mungbean, foliar development is normally slow during the early life of the plant (Kuo, Wang, Cheng, and Chow, 1978). Without vigorous early growth, there will be inadequate functional leaf area (source) at the onset of flowering to produce the assimilate needed during pod formation and seed development.

Mungbean is indeterminate in flowering habit, flowering and fruiting continuing over a period of several weeks, if the plant remains healthy. During this period there is competition for available assimilates between the vegetative sinks and the reproductive sinks. When anthesis begins, the supply of assimilate from source leaves needs to be diverted away from vegetative sinks and into fruiting sinks if large seed yields are to be obtained (Clifford, 1979; Pawar and Bhatia, 1980). This suggests that efforts should be made to increase leaf area (source) prior to anthesis by (*a*) cultural practices, such as closer spacing, fertilization, and insect and disease control, and (*b*) genetic selection for strains in which vegetative growth diminishes with flowering, so that assimilate produced during the flowering period is largely partitioned into the seed. Some strains with the latter characteristic have been reported (AVRDC, 1978A). The effects of closer spacing and other cultural practices to increase the leaf index may be partially offset if the practice results in mutual shading and reduced light interception.

Comparisons of Mungbean Growing Seasons

Having considered the climatic factors that affect the production of mungbeans, it will be of interest to examine the performance of mungbeans growing in different climatic situations. Six examples from the 2nd, 3rd, and 4th International Mungbean Nurseries (IMN) are compared. Information on the locations and performance are reported in Table 4. Precipitation received at each nursery site is given, but temperature data are from long term averages for the respective locations, since data for the exact growing periods were not available. The mungbean response is characterized by the location effect on the length of the growing season, the days to first flowering, height, and seed yield. All data are means of 30 varieties growing in the IMN nursery for that year. The seed yields are influenced by the soil fertility conditions at the different stations in addition to the climatic influences. The Tha Phra data was taken from the 2nd IMN;

Table 4. Performance of Mungbean Grown in Different Climatic Conditions.

Location	Latitude	Elevation	Precipitation	Irrigations	Mean Temperature	Date Planted	Growing Season	Flowering	Height	Seed Yield
		m	mm	number	°C		days	days	cm	kg/ha
				Rainy Season, Low Latitude						
Los Baños, Philippines[a]	14° N	15	476	none	28	June 20	61	34	67	558
				Dry Season, Low Latitude						
Los Baños, Philippines[b]	14° N	15	5	(?)	25	Jan. 9	81	33	26	169
				Summer Season, Low Latitude						
Tha Phra, Thailand[c]	16° N	178	325	2	29	May 10	68	32	43	341
				Summer Season, High Latitude						
Karaj, Iran[a]	35° N	1300	none	12	26	June 3	142	56	40	1262
Stillwater, Oklahoma[b]	36° N	274	367	none	23	May 30	137	53	43	1193
Morden, Canada[b]	49° N	311	161	none	17	June 1	181	71	35	d

[a] Poehlman, Sechler, Swindell, and Sittiyos (1976).

[b] Poehlman, Sechler, Watt, Swindell, and Aggarwal (1975).

[c] Poehlman, Sechler, Yohe, Watt, Swindell, and Benham (1974).

[d] Only seven strains matured seed.

Los Baños (Jan. 9), Stillwater, and Morden data were taken from the 3rd IMN; and the Los Baños (June 20) and Karaj data from the 4th IMN. Entries differed slightly in the three nurseries.

The locations selected are representative of several different growing conditions: rainy, dry, and summer seasons at low latitudes, and summer season at a high latitude.

(a) Rainy Season, Low Latitude. In Southeast Asia, many mungbean are grown during the rainy season of a monsoon climate. The nursery grown at Los Baños is typical. Being planted at the beginning of the rainy season, the abundant rainfall and dark cloudy weather resulted in the plants growing tall, and the short photoperiod and high mean temperature resulted in early flowering and a short growing season.

(b) Dry Season, Low Latitude. Seeding after lowland rice is the most common planting procedure for mungbean in Southeast Asia. The mungbean uses residual moisture in the soil after the rice is harvested. The nursery seeded at Los Baños on January 5 received only 5 mm precipitation. The moisture stress resulted in short plants and low yields. With the short photoperiod, flowering occurs early, but the total growing season is longer than in the preceding example due to the lower mean temperature.

(c) Summer Season, Low Latitude. In India, Taiwan, and Thailand, short season varieties of mungbean are grown during the hot summer (March to May), prior to the onset of monsoon rains in a multiple cropping program. Growing mungbean in this season is feasible if irrigation water is available and its use economical. Mungbean grown in this season flowers early and has a short fruiting period due to the high mean temperatures. In Thailand, the summer plantings differ from those in India in that they are timed to utilize early summer rains, which reduces the number of irrigations needed (Schiller and Dogkeaw, 1976). The IMN grown at Tha Phra, Thailand, was grown under the latter conditions. The short photoperiod and high temperature results in early flowering and a short growing season.

(d) Summer Season, High Latitudes. At high latitudes mungbean is grown during the summer and must mature and be ready to harvest before frost occurs. The long photoperiod and lower mean temperatures combine to delay flowering and extend the length of the growing season. The Karaj climate differs from that at Stillwater by being devoid of rainfall, the crop being grown entirely from irrigation water, and by having a higher elevation. Under these conditions solar radiation at Karaj is high. The mean maximum temperature was 33°C compared to 30°C at Stillwater. In Oklahoma, mungbeans are double-cropped with winter wheat.

At the high latitude of Morden, Canada, flowering is delayed and the growing season is longer than that at Karaj and Stillwater. Only 7 of the 30 mungbean strains matured seeds before the first frost on October 9.

The duirnal temperature range differs at the different locations but its effect on mungbean has received little study. Differences between the mean minimum and mean maximum temperatures were 9°C at Los Baños (July 9 planting date), 13°C at Stillwater, and 15°C at Karaj. Lawn (1979) reported that varieties of mungbean differ in sensitivity to maximum and minimum temperatures. How this response affects the adaptation of varieties in different climates has not been studied.

V SOIL REQUIREMENTS

Mungbean is grown on a wide range of soil types. For highest yields, a warm, deep, well-drained loam or sandy loam is desirable. Deep loam soils are moisture retentive and light soils facilitate internal drainage. The mungbean is seldom fertilized, its growth and production, except for nitrogen, being dependent on soil nutrients already present, or from residual fertilizers applied to the preceding crop. Being a legume, the mungbean can utilize nitrogen assimilated in root nodules through a symbiotic relationship with soil rhizobia. For nodule formation to take place, the proper strain of rhizobia and a soil environment suitable for the rhizobia to function must be present. Heavy soils and waterlogged soils are unsatisfactory for production of mungbean, blackgram being superior to mungbean under these conditions.

Soil Structure and Root Development

The general recommendation for a deep, well-drained loam or sandy loam for mungbean is based on long experience (Roberts and Singh, 1947; Mehta, 1955; Aiyer, 1958; Doherty, 1963; H. B. Singh, Joshi, and Thomas, 1970; and PCARR, 1977). Aeration, internal drainage, and tilth are superior in light soils to that found in heavy, fine-textured soils. The superior tilth of light soils permits rapid seed germination, quick seedling establishment, and deep root penetration. On heavy soils, poor stands are common, due to poor seedling emergence, resulting in low mungbean yields.

It is often stated that mungbean has an extensive and deep root system which contributes to drought tolerance. This viewpoint is being questioned at AVRDC after observations that mungbean is sensitive to variations in environmental stress caused by drought (H. G. Park and C. Y. Yang, personal communication, 1980). If mungbean has an extensive root system, then sensitivity to moisture stress should be minimal. In an early experiment, Bose and Joglekar (1933) described two root system patterns in mungbean varieties: (*a*) a profusely branched, shallow root system, 11 to 17 cm in depth, which the plant depends upon for its moisture supply, combined with a sparse tap root system; and (*b*) a sparsely developed shallow root system with a tap root system which penetrates to about 100 cm, capable of drawing soil moisture from greater soil depths. Mungbean strains with root characteristics of the first type would be less tolerant to declining soil moisture levels than those of the second type. Studies are needed to characterize the root growth patterns of presently grown mungbean varieties under different soil moisture levels. Comparisons with root development of other grain legumes grown under similar soil structure and moisture situations are needed to shed light on the question of the relative drought tolerance of mungbeans. It would also be of interest to examine reasons for the reported superior adaptation of blackgram to heavy and waterlogged soils.

Nitrogen Nutrition

Legumes, such as mungbean, through association with particular soil bacteria, produce root nodules in which atmospheric nitrogen is fixed into a form available for use by the plant. This symbiotic relationship is beneficial to the mungbean host plant by providing a source of the nitrogen required for plant growth and development. Application of nitrogen fertilizer to mungbean will reduce the amount of nitrogen fixed by the rhizobial organism. The soil requirements for the nitrogen nutrition of mungbean is thus determined not as much by the potential nitrogen supply in the soil, as by the suitability of the soil environment to support rhizobial activity. The biological nitrogen fixation process as related to mungbean will be discussed in a later topic.

Mineral Nutrition

(*a*) Phosphorus. Phosphorus is an essential constituent of nucleoproteins, phospholipids, enzymes, and other plant substances. Phosphorus is essential for energy storage and release in the living cell. It functions in the formation and translocation of carbohydrates, in crop maturation, root development, and resistance to certain diseases. It is concentrated in cells with high metabolic activity such as meristems, and is stored in the seed. When phosphorus is limited, plants will be stunted, have dark green leaves, and be low in protein content.

Total phosphorus content of the soil is low, in the order of 0.01 to 0.20% (Brady, 1974). Furthermore, in acid soils it is commonly "fixed" as iron- or aluminum phosphate compounds which have low solubility. In acid soils of the tropics, phosphorus deficiency is a common limitation to plant growth. The limitation is pronounced for legumes, such as mungbean, that utilize symbiotically fixed nitrogen in their growth. This is due to the vital role played by phosphorus in reactions involving energy, such as ATP in nitrogenase activity (Franco, 1977). The tendency of soils to fix phosphorus is partially counteracted at a pH of 6.2 to 6.5, or with high organic matter. Yields of mungbean in India and other tropical countries usually respond favorably to phosphate fertilization indicating that this element is generally deficient in weathered soils of tropical and subtropical regions where mungbean is grown.

(*b*) Potassium. Potassium has many functions in plants. It aids in photosynthesis, enzyme action, and sugar and starch translocation; reduces respiration thereby preventing energy loss; aids drought tolerance by maintaining turgor, reducing water loss, and increasing root growth; reduces lodging by increasing cellulose; and helps to retard disease. Potassium is more abundant in soils than phosphorus, occurring in the range of 0.17 to 3.30% (Brady, 1974). It tends to be chemically bound in insoluble mineral forms from which it becomes slowly available for plant growth as an exchangeable cation. Potassium is removed from the soil through crop plants, and it is also lost from the soil by leaching. Application of lime aids in fixation of the potassium and reduces the loss from leaching as compared to acid soils. Although potassium has a favorable effect on dry matter production in legumes, its role in nitrogen-fixation is not fully understood. There have been relatively few fertilizer experiments with potassium on mungbean suggesting that potassium deficiency has not been considered to be a serious problem on soils where mungbean is grown. For soybean, it has been shown that available potassium is generally inadequate in sandy soils and soils of the humid region, but is generally sufficient in subhumid regions (Kurtz, 1976). This generalization probably applies to mungbean also.

(C) Other Elements. Other elements essential for plant growth include calcium, magnesium, sulfur, molybdenum, zinc, iron, manganese, boron, and copper. Calcium is a key element in growing legumes, having an important role in nodule formation and symbiotic nitrogen fixation. In addition to serving as a nutrient, calcium as $CaCO_3$ has a neutralizing effect on soil acidity. Calcium and magnesium are commonly deficient in the highly weathered soils in the humid tropics. These elements may be supplied to the soil in agricultural limestone, which also increases soil pH. Liming to increase soil pH, will increase availability of phosphorus and molybdenum and diminish toxic levels of aluminum, manganese, and iron. Soil with a pH range of 5.8 to 6.5 is considered ideal for mungbean (Tucker and Matlock, 1969) and a pH of 6.5 is optimum for symbiotic nitrogen fixation (PCARR, 1977). The nitrogen fixing activity may be affected adversely by deficiencies in calcium, molybdenum, and boron.

Sulfur is a constitutient of leaves and the essential amino acids, methionine, cystine, and cysteine, found in seeds of mungbean (Arora and Luthra, 1971A and 1971B). The quantity of the sulfur bearing amino acids in mungbean seeds are too low to provide a balanced diet if mungbean seed is eaten alone. These amino acids were increased by application of sulfur to mungbean growing in pot cultures (Aulakh and Pasricha, 1977).

The extent to which soil deficiencies in micronutrients affect yields of mungbean has not been carefully assessed. Franco (1977) lists the major barriers to yield increases in tropical grain legumes as lack of sufficient water, absence of proper *Rhizobium* strains, and deficiencies in soil nutrients. The major deficiency among the mineral nutrients would appear to be in phosphorus, judging from the yield increases obtained by applications of phosphate fertilizers. Until major soil factors limiting mungbean growth such as deficient moisture and low phosphorus availability are corrected, deficiencies of secondary and micronutrients will go largely unnoticed and certainly uncorrected. Because mungbeans are widely grown on acid soils, calcium and molybdenum may frequently be deficient. A zinc deficiency was reported in mungbean growing on a calcarious soil in Taiwan (AVRDC, 1975).

Genetic variability in mungbean for tolerance to micronutrients has received only minor study. Comparisons are needed of mungbean with closely related species, and among mungbean varieties. In a comparison of mungbean with black and red beans (*Phaseolus vulgaris*) for tolerance to boron deficiency, mungbean and red beans were more tolerant than black beans (Howeler, Flor, and Gonzalez, 1978). Tolerance to aluminum toxicity is found in certain varieties of small grains but does not seem to have been studied in mungbean. Tolerance in mungbean to some of these unfavorable soil conditions would extend the range of soils on which mungbean could be grown.

(d) Soil Nutrient Level. Soil analyses can be used to measure soil acidity and relative levels of phosphorus, potassium, and other essential plant nutrients.

Mycorrhiza

Mycorrhizal fungus invading the plant root cortex increases the feeding zone of plant roots since the external hyphae extend out farther than the root hairs. Ions absorbed into the fungus roots, principally phosphate, with zinc and molybdenum to a lesser extent, upon release become available to the host plant roots. From there they may be transferred into nodules in leguminous species (Mosse, 1977). While favorable yield response to mycorrhizal activity has been reported for soybean (Ross, 1971), the response of mungbean is unknown.

VI BIOLOGICAL NITROGEN FIXATION

Nitrogen is an essential constituent of plant protoplasm. It enters into the synthesis of amino acids, proteins, alkaloids, chlorophylls, soluble nitrogen compounds, and other complex plant products. Plants abundantly supplied with nitrogen are thrifty, grow rapidly, and have a dark green color; a deficiency is marked by slow growth, a stunted plant, an' a pale green color. Soil nitrogen is a transient and renewable resource. Originating from the atmosphere, it is stored in the soil organic matter. As the organic matter decomposes, ammonia is released, with the ammonia being further oxidized to nitrites and nitrates. The plant may utilize some of the ammonia, but principally it utilizes nitrates in the production of new organic matter. Additionally, elemental nitrogen and ammonia may be lost by denitrification or volatilization into the atmosphere, and nitrates may be lost by leaching from the soil in soil water. The soil supply of nitrogen is renewed by the incorporation of organic materials, addition of nitrogen chemical fertilizers, or through biological nitrogen fixation.

To augment the soil nitrogen supply for intensive crop production, large quantities of commercially manufactured nitrogen fertilizers are being utilized, mostly in the developed countries. Since about 1973, the price of nitrogen fertilizer has risen drastically, and it continues to rise. In the process of manufacturing nitrogen fertilizer, large quantities of fossil fuels and energy are utilized. The high cost of energy has increased the cost of nitrogen fertilizer to the point that its use is being restricted in the developed countries, and largely prohibited in the less developed countries where food production needs are greatest. In addition, response to the use of nitrogen fertilizer, as measured by increased crop yields, is not always as large in tropical climates as in temperate climates, due to soils being inherently low in organic matter, and to excessive losses from leaching and denitrification. These problems emphasize the need for greater utilization of biological nitrogen fixation to increase crop production in the tropics.

The most effective system of biological fixation of nitrogen involves the symbiotic relationship between bacteria of the genus *Rhizobium* and plants of the family Leguminosae. In this system, bacteria living in nodules on roots of legume plants convert nitrogen from the atmosphere into forms which can be utilized by the plant. Being a legume, the mungbean has the potential for fixing atmospheric nitrogen in root nodules through symbiosis with appropriate species of *Rhizobium*.

Cowpea Cross-Inoculation Group

Species of *Rhizobium* are delineated according to their ability to nodulate certain groups of leguminous plants. The bacteria-plant groups are referred to as cross-inoculation groups. The *Rhizobium* strains in the soil which nodulate mungbean, and related tropical grain legumes such as blackgram, cowpea, and pigeon pea, are identified as the cowpea cross-inoculation group. The organisms of this group have not been given a species designation and are traditionally referred to as *Rhizobium* sp., with such common names as cowpea rhizobia, cowpea-type rhizobia, cowpea cross-inoculation group, or cowpea miscellany. The absence of species designation in the cowpea cross-inoculation group sometimes leads to cowpea rhizobia being confused with *Rhizobium japonicum*, which nodulates and fixes nitrogen only in soybeans, or *Rhizobium phaseoli*, which nodulates and fixes nitrogen only in common beans. Inoculants of the latter species will not cause nodulation in mungbean.

Strains of *Rhizobium*

The *Rhizobium* organisms, in addition to being differentiated into species and cross-inoculation groups according to infectivity of different leguminous species, may be further differentiated into strains which differ in efficiency of nitrogen fixation within a particular leguminous species. The strains may be isolated from nodules of different plant species, or from different plants of the same species. In a study of *Rhizobium* isolates from 12 species of legumes, isolates from mungbeans, peanuts, pigeon pea, and blackgram were grouped together on the basis of antigenic properties (Dadarwal et al., 1977). When the plant species were cross-inoculated with the different *Rhizobium* isolates, the host plants showed symbiotic promiscuity in the order *Vigna radiata* > *Arachis hypogaea* > *Cajanus cajan* > *Vigna mungo*. These results indicate that mungbean may be nodulated by a wide range of strains of cowpea-type rhizobia that may be present in tropical soils. Strains of *Rhizobium* which differ in ability to nodulate mungbeans are being collected by the University of Hawaii through the project on Nitrogen Fixation of Tropical Agricultural Legumes (NifTAL) and at other locations. The NifTAL project is sponsoring inoculation trials with different rhizobial strains on mungbean and other legumes at various locations in tropical countries in order to compare the effectiveness of the strains in different environments.

In India, grain yields of mungbean were compared after inoculation with cultures isolated from mungbean, blackgram and peanut (Oblisami, Balaraman, and Natarajan, 1976). The highest yield was obtained following inoculation with the *Rhizobium* culture isolated from peanut. Composites of cultures from mungbean and blackgram, and from mungbean and peanut, gave higher yields than the culture from mungbean alone. Strain differences could not be detected following inoculation with cultures of *Rhizobium* isolated from healthy mungbean plants and from plants infected with yellow mosaic virus (Venkataraman and Subra Rao, 1974). The promiscuity of mungbeans for infection with native strains already present in the soil reduces the effectiveness of efficient strains which may be utilized as inoculum.

Potential of Mungbean for Nitrogen Fixation

The organic matter content of tropical soils is normally maintained at a low level. Increasing the organic nitrogen level of the tropical soils through biological nitrogen fixation will require extensive cultivation of well nodulated leguminous crops. Only limited information is available on the effectiveness of mungbeans for nitrogen fixation, either alone or in comparison with other legume species.

Masefield (1961) used fresh weight of nodules and number of nodules to compare the nodulation of annual tropical leguminous crops. The nodulation of mungbean exceeded that of soybean and cowpea at two locations in Malaysia, but was lower than the nodulation of the winged bean (*Psophocarpus tetragonolobus*). Although the amount of nodulation varied with the location, generally it was lower than commonly reported from temperate climates. Date (1977A) reports that nitrogen fixation of tropical pasture legumes ranges from 20 to 180 kg/ha/year. The amount varies with the legume, the strain of *Rhizobium*, soil moisture, temperature, soil mineral supply, pH, and other factors. Greenland (1977) suggests that nitrogen fixation in the range of 100 kg/ha/year may be expected in certain tropical soils. In India, Subba Rao (1975) reported that blackgram added 8 kg/ha nitrogen without *Rhizobium* inoculation and 131 kg/ha with inoculation.

In a pot experiment conducted in Nigeria, uninoculated mungbean fixed 85 mg/pot of nitrogen compared to 9.3 g/pot for inoculated mungbean (Agboola and Fayemi, 1972). The amounts of nitrogen fixed were estimated to be equivalent to 63 and 224 kg/ha, respectively, and compared with estimates of 157 and 354 kg/ha for uninoculated and inoculated cowpeas. These estimates of nitrogen fixation, based on extrapolation of results from pot experiments to a hectare basis, seem excessive when compared with measurements of nitrogen fixation in field experiments. In a two-year field study in Thailand, involving both dry and wet season cropping combinations, nitrogen fixation ranging between 58 and 107 kg/ha/season was reported for mungbean (Firth et al., 1973). This would appear to be a realistic range for potential nitrogen fixation by mungbean under favorable conditions. The actual nitrogen fixation by much of the mungbean in farmers fields is probably quite low, since the crop is widely grown on soils of low fertility with poor cultural practices. More information is needed on nitrogen fixation by mungbean under specific soil conditions, as well as comparisons with other legume species such as cowpea and soybean.

Nitrogen fixation in nodulated roots of mungbean plants was measured, using the acetylene reduction technique, over the life of the plant at AVRDC in Taiwan (AVRDC, 1978A; Talekar and Kuo, 1979). Acetylene reduction activity was barely detectable during the three-week period following planting. It increased rapidly thereafter, reaching a peak at nine weeks, then declined until barely detectable again at 12 weeks. The decline did not start until about two weeks after flowering began, but continued through the pod-filling period. The increase in acetylene activity through the first two weeks of flowering was thought to be due to lack of senescence in mungbean so that photosynthetic activity continued at a high level. The low acetylene activity during the first three weeks is of interest in view of the report by Kuo et al. (1978) that mungbeans grow slowly during the first three weeks after emergence. Mungbean varieties differed in acetylene activity in the AVRDC study. Nitrogen fixation was reported for individual plants and could not be extrapolated to kg/ha.

Nitrogen Transfer to Other Crops

Mungbeans are grown extensively as a short duration crop in rotation with rice, wheat and other crops. Where a legume is grown in rotation with another crop, transfer of nitrogen occurs as a result of decomposition of the legume residue, including the roots and the nodules, and subsequent utilization of the nitrogen by the succeeding crop. The potential nitrogen transfer is reduced by removal of seed and plant materials at harvest. If planting of the succeeding crop is delayed, some of the nitrogen released by decomposition of the residue may be lost from the soil. How much nitrogen mungbean will release and whether it would be the appropriate legume to grow in the cropping system will depend upon the specific situation. In practice, the choice of the legume to grow in a particular rotation is usually based on how it fits into the cropping sequence and its commercial value rather than on its nitrogen fixing potential.

Mungbean may be intercropped with sugarcane, cotton, jute, maize, pearl millet, sorghum, or pigeon pea, by growing in alternate rows. Mixed cropping of mungbean with other crops is also practiced in the tropics. How much the nonlegume crop benefits from the biological nitrogen fixation associated with the legume is difficult to assess. If planted at the same time, both crops will compete for mineral nitrogen in the soil, and, where nitrogen is limited, uptake for both crops may be reduced. The competition may be minimized by seeding the legume after the companion crop is established (Henzell and Vallis, 1977). The nonlegume will benefit most if the legume reaches physiological maturity and dies before the nonlegume crop has completed growth. In this situation nitrogen immediately released from decomposition of the legume residue could be utilized by the companion crop. Because mungbean is a short duration legume, it would have a distinct advantage over long duration legumes for utilization in intercropping systems in this manner.

Although numerous research reports on intercropping with legumes in general, and mungbean in particular, have been published in recent years, the results are often inconclusive or conflicting. They suggest that (*a*) mungbean may be an effective host in the biological nitrogen fixation process, (*b*) under favorable circumstances, mungbean will fix from 50 to 100 kg/ha of nitrogen, (*c*) some nitrogen transfer from the mungbean to the companion nonlegume may take place during the growing season, although the major benefit will be to the succeeding crop, and (*d*) the nitrogen supply will be reduced by removal of plant and seed material at harvest, or by leaching before the succeeding crop is planted.

Inoculation of Mungbeans

The benefits of inoculation on yield of legumes grown in soil devoid of an infective strain of *Rhizobium* is well established (Erdman, 1967). *Rhizobium* inoculation of mungbean in the absence of natural inoculum may be expected to produce higher yields if (*a*) an infective and viable strain of *Rhizobium* is used, (*b*) the inoculation procedure is carried out with care so that viable bacteria are introduced into the soil, and (*c*) the soil environment is favorable for the bacteria to survive and develop healthy nodules on the mungbean root.

Yield increases in mungbean of 10 to 37% following inoculation have been reported by various research workers in India (Table 5). An increase of 38% was reported for blackgram (Reddy, Zaheda, and Rao, 1978). Sheriff et al. (1970) failed to obtain an increase in yield with inoculation. They did not report on nodulation of either the inoculated or uninoculated plants, so it is not known whether native strains produced nodules on the uninoculated plants or whether the inoculated culture failed to produce nodules. P. Singh and Choubey (1971) reported a profit/cost ratio of 27/1 for inoculation with their *Rhizobium* strain A.

Table 5. Yield Increase in Mungbean from Inoculation with *Rhizobium* Cultures.

Reference	Seed Yield, Uninoculated	Seed Yield, Inoculated	Yield Increase
	kg/ha	kg/ha	%
Rajagopalan et al. (1965)	206	226	10
Singh, P. and Choubey (1971)			
Strain A	1,073	1,356	26
Strain B	1,073	1,231	15
Strain C	1,073	1,270	18
Maheshwari (1974)	613	775	26
Pawar and Ghulghule (1977)	598	750	16
Singh, S. D. (1977)	467	639	37

(*a*) Need for Inoculation. Inoculation will usually be beneficial if uninoculated plants have poor growth and nodulation, but respond to nitrogen fertilizer (Date, 1977B). If inoculated plants fail to make comparable growth to those receiving nitrogen fertilizer, then the strain of *Rhizobium* may be ineffective, or there may be some condition in the soil that makes the rhizobia ineffective.

(b) Strain of *Rhizobium*. Mungbean is widely regarded as symbiotically promiscuous, nodules being produced when infective strains of the cowpea cross-inoculation group of *Rhizobium* are present in the soil. Strains within the group differ in how effectively they nodulate mungbean. P. Singh and Choubey (1971) obtained seed yield increases of 26%, 15%, and 18%, respectively, from inoculation with three strains of *Rhizobium* above the yield of an uninoculated check (Table 5). For a strain to be effective it should produce nitrogen fixing nodules in a wide array of soil conditions and be competitive in nodule formation and nitrogen fixation with less effective strains already present in the soil.

(c) Inoculant Preparation and Use. Procedures for preparation of legume inoculation are described by Roughley (1970), Vincent (1970), Date (1977B), and others. Legume inoculant cultures are usually prepared by mixing a *Rhizobium* broth culture with finely ground, sterile peat as a carrier. The bacteria and peat mixture are mixed with gum arabic or a sucrose solution so that the mixture will adhere to the seed. The storage life of the culture depends upon the temperature and humidity at which it is stored. Viability may be maintained for as long as one year at temperatures of 5° to 10°C, or as short as 8 to 10 weeks at temperatures of 20° to 25°C (Vincent, 1970). In order for the inoculation to be successful, Ayanaba (1977) recommends that 1,000 to 10,000 bacteria of a suitable strain should be applied to the surface of a seed, however, some researchers would increase this number by as much as tenfold. Inoculated seeds need to be dried immediately and, preferably, planted the same day. Exposure of inoculated seed to direct sunlight or high temperatures must be avoided. Inoculated seed planted in open furrows should be covered immediately. Inoculated seed should not be treated with toxic chemicals, mixed with fertilizer, or planted in a furrow in contact with fertilizer.

(d) Seed Pelleting. Inoculated seed may be pelleted to protect the bacteria and correct adverse soil conditions in the vicinity of the seed (Roughley, 1970; Date, 1977B). After inoculum has been applied to the seed as a slurried peat culture containing an adhesive, the moist seed is coated with finely ground limestone or rock phosphate. Limestone increases the pH, neutralizing the detrimental effects of acid soil in contact with the seed. In alkaline soils in India, pelleting mungbean seed with calcium sulfate gave beneficial effects. Chhonkar, Iswaran, and Jauhri (1971) reported that mungbean seeds inoculated and coated with calcium sulfate produced 82 nodules per plant compared to 66 nodules for seed inoculated and coated with limestone, 28 nodules for seed inoculated without pelleting, and 2.7 nodules for uninoculated seed. The seeds were planted in a saline, alkali soil, pH 8.0. Also, in an alkaline soil, pH 8.9, Gupta et al. (1976) obtained an increase in seed yield over the uninoculated check of 24.7% with inoculated seed pelleted with calcium sulfate, compared to a 19.4% increase with inoculated seed pelleted with calcium carbonate, 17.6% increase with inoculated seed pelleted with rock phosphate, and 5.8% increase for inoculation without pelleting. In phosphate deficient soils in the tropics, rock phosphate may be preferred to limestone as the pelleting material (Diatloff, 1971). Pelleting the seeds improves survival of the bacteria until they colonize the root, and increases chances of successful nodulation if seed germination is delayed. Pesticides may be incorporated with pelleting materials, but only if it has been proven that they have no adverse effects on the bacteria.

Factors Affecting Nodulation

Tropical and subtropical environments where mungbean is mostly grown are generally less favorable for nodulation than temperate environments. Studies of environmental effects on nodulation of mungbean are meager, but information gathered on conditions favorable for nodulation of other annual legume crops in the tropics will generally be applicable to mungbean.

(*a*) Physical Environment. The physical environment in which nodulation takes place may be affected by light, temperature, soil moisture, aeration, pH, salinity, and other factors (Masefield, 1958). In the tropical areas, climatic factors such as length of day and cloud cover during the rainy season reduce the amount of light, adversely affecting the vigor and growth of the host plant. In a study conducted in a controlled environmental chamber, both short days and low light intensity limited nodulation and nitrogen fixation in cowpea, soybean, and common bean (Dart, 1973). These data suggest that shading mungbean when intercropping could reduce nodulation. High soil temperatures may restrict nodulation and nitrogen fixation. Cowpeas nodulate best and fix the most nitrogen with a day temperature of 27°C and a night temperature of 24°C (Dart, 1973). Nodulation decreased as day temperatures were increased; with a 36°C day temperature and a 21°C night temperature, nodulation and nitrogen fixation were poor. *Rhizobium* strains differed in their effectiveness at the high temperatures. While these results were reported for cowpea, mungbean nodulates with the same group of rhizobial strains. An upper temperature limit of around 36°C was noted also for nodulation in beans (Graham and Halliday, 1977).

Soil moisture stress limits root development and vegetative growth, and hinders effective nodulation and nitrogen fixation. Excess water reduces the oxygen supply in the soil required for respiration of *Rhizobium* bacteria, and reduces the nitrogen supply required for nitrogen fixation. During long periods of waterlogging, nodules and outer root tissue sloughs off (Hinson and Hartwig, 1977), causing a temporary nitrogen deficiency. Mungbean is frequently planted after lowland rice, but there is little information on the effect of flooding over long periods on natural soil rhizobial populations.

Soil acidity is inimical to rhizobial activity and nodulation, although rhizobia of tropical legumes are reported to tolerate soil acidity better than rhizobia of temperate climate legumes. A pH of 6.5 appears to be optimum for mungbean rhizobial activity (PCARR, 1977), with a minimum for activity of about pH 3.5 to 4.0 (Yadav and Vyas, 1971). Rhizobial strains vary in their tolerance to low pH. Munns et al. (1979) compared nodulation of 40 rhizobial strains applied as inoculants to two mungbean strains on a soil with a natural pH of 5.0 and the same soil limed to a pH of 6.5. A few rhizobial strains failed to nodulate mungbean at pH 5.0; with about one-half of the rhizobial strains, the nodulation was significantly impaired at pH 5.0; the remaining rhizobial strains nodulated mungbean at both pH values, some more effectively at the low pH than others. Usually, the effectiveness with which the rhizobial strain nodulated mungbean at the low pH was sirilar for the two mungbean host strains. However, a few rhizobial strains were tolerant of low pH on one mungbean host strain and not the other. The interaction of rhizobial strain with mungbean genotype suggests that the search to find tolerant rhizobial strains will require that they be tested on a range of mungbean gentoypes, thereby greatly increasing the labor involved in the testing process.

(*b*) Mineral Nutrition. Mineral nutrients necessary for rhizobia to survive, multiply, and nodulate legume plants include phosphorus, sulfur, calcium, potassium, and traces of molybdenum, boron, copper, zinc, cobalt, and manganese (Vincent, 1970). Other soil conditions that may limit nitrogen fixation are soil acidity, aluminum and manganese toxicity (Franco, 1977), and soil salinity. Available phosphorus is often the major limiting element in tropical soils, but deficiencies in molybdenum, sulfur, calcium, and boron should not be overlooked (Andrew, 1977). The benefits to nodulation and nitrogen fixation of mungbean by correcting phosphate deficiencies have been demonstrated in India (Khare and Rai, 1968; Sahu and Behera, 1972; and Ravankar, Badhe, and Kadwe, 1972/73). Increased yield of mungbean by correcting a zinc deficiency was reported by Ghildiyal, Saini, and Sirohi (1975). Soil mineral deficiencies that reduce the effectiveness of nodulation and nitrogen fixation in mungbean are site-specific, and need to be correctly identified in order to determine the kind and amount of fertilizer to apply to correct the deficiency.

(*c*) Nitrogen Nutrition. The uniqueness of the symbiotic process is the capability of utilizing atmospheric nitrogen to meet the nitrogen requirements for growth of the legume plant. This does not preclude the uptake by the plant of mineral nitrogen from the soil (Bouldin et al., 1979). If the soil supply of nitrogen is abundant, then most of the nitrogen used by the legume plant will come from the soil. If the soil supply of nitrogen is low, then the legume plant will obtain most of its nitrogen from symbiosis, assuming that the proper strain of *Rhizobium* is present in the soil, and that the environment and soil mineral supply are favorable for the nitrogen fixing process to be consummated.

Supplementation of the symbiotically fixed nitrogen supply by nitrogen fertilizer has been considered as a means of increasing plant growth. Research has generally shown that the symbiotic nitrogen fixation process does not function efficiently if large quantities of nitrogen fertilizer are applied to legume plants. In that case, nitrogen fixation is reduced in proportion to the amount of nitrogen applied (Hinson and Hartwig, 1977). An exception may be the application of a nitrogen starter fertilizer to legumes seeded in nitrogen deficient soils in order to stimulate early seedling growth. Bacterial invasion of the root cortex and initial development of nodules requires about 20 to 25 days. This represents a large portion of the life of a short duration legume such as mungbean. Under high-temperature/short-day environments the mungbean may flower within 30 to 40 days following emergence and be mature within 60 to 70 days. Application of nitrogen starter fertilizer for utilization by the mungbean plant during the period of juvenile growth may have special merit because early growth of mungbean is normally slow (Kuo, Wang et al., 1978).

The question is how much nitrogen to apply without delaying maturity and unnecessarily reducing symbiotic nitrogen fixation. In the Philippines, a starter application of 20 kg/ha of nitrogen is recommended for mungbean (PCARR, 1977). At AVRDC, in Taiwan, the recommendation is for 15 kg/ha nitrogen at planting time, and an additional 15 kg/ha at flowering to meet the heavy demand for nitrogen during the period of pod filling (Park, 1978A). As with mineral nutrients, the desirability of applying nitrogen fertilizer will depend upon the specific soil fertility conditions of the field. The first step should be to insure that *Rhizobium* strains of the right kind are present, and that soil mineral needs and other conditions conducive to good nodulation are met.

(*d*) Other Factors. *Rhizobium* strains differ in competitive ability for nodule sites in legume plants when more than one strain is present (Johnson, Means, and Weber, 1965; Caldwell, 1969; Brockwell and Gault, 1973). The ability to compete for a nodulation site and the effectiveness in nodulation and nitrogen fixation after the bacterial strain has invaded the host plant root are desirable characteristics of rhizobial strains. Mungbean growing in tropical or subtropical areas may be infected by strongly competitive native *Rhizobium* strains of the cowpea cross-inoculation group which may, or may not, be effective nodulators. While competitive ability and effectiveness are not precluded from being in the same strain, a strongly competitive, ineffective strain may reduce the benefits that could be obtained from an effective strain that is less competitive.

Nodule formation and nitrogen fixation may be affected by various disease producing organisms, viruses, nematodes, seed exudates, or seed treatments. Nodule number, weight, and size in mungbean were reduced by infection of the host plant with arhar mosaic virus (AMV) (R. Singh and Mall, 1974). Seed exudates from mungbean that were phenolic in character had an inhibiting effect on rhizobial growth (Dadarwal and Sen, 1973; Kandasamy and Prasad, 1979). Root nodulation may be adversely affected by accumulated pesticide residues, or by pesticides applied at excessive rates (Gaur and Pareek, 1969; Pareek and Gaur, 1970; Gaur and Varshney, 1974; Staphorst and Strijdom, 1976; and Chaudhury et al., 1977).

Favorable effects on nodulation and nitrogen fixation have been reported by applications to the soil of organic matter (Rajagopalan and Sadasivan, 1964) and humic acid extracted from farmyard manure (Khandelwal and Gaur, 1970). A synergistic effect from seed inoculation of mungbean with *Rhizobium* and *Azotobacter* has been reported (Pawar and Ghulghule, 1977).

VII PRODUCTION

Mungbeans are grown over a broad range of soil fertility and moisture conditions and with varying levels of cultural practices and technology. At the low end of the technology scale is the subsistence farmer who broadcasts mungbean seed in rice stubble after the monsoon rains have ended. He has neither the equipment to prepare a suitable seedbed, nor irrigation facilities to replenish deficient soil moisture. Fertilization is not practiced, and normal growth stops when the moisture supply is exhausted. Weeding and harvesting are performed with hand labor. In contrast, mungbean production in more developed areas may be carried out with highly mechanized equipment, from seedbed preparation to combine harvesting. Weeds are controlled by selective herbicides, and soil nutrient needs are carefully corrected as determined from soil test specifications.

Place in the Cropping System

Mungbean is a short duration crop, adaptable for use in multiple cropping systems. Earlier, most varieties grown were photoperiod sensitive requiring 80 to 95 days to mature, but presently, new varieties are being developed with low photoperiod sensitivity which can be harvested in 60 to 75 days. This increases the flexibility of fitting mungbean into intensive cropping patterns. Mungbean is planed in three types of multiple cropping systems, (*a*) *relay cropping*, in which mungbean is planted in sequence with other crops, (*b*) *intercropping*, in which mungbean and another crop are interplanted in alternate rows, (*c*) *mixed cropping*, where crops are planted together in mixtures.

In *relay cropping*, mungbean is grown as a secondary crop. The primary crop, commonly rice or wheat, but sometimes maize or sorghum, is given priority for the season in which it is grown, with mungbean being fitted into the sequence before or after the primary crop. In the tropics, the rainfall pattern is the major climatic factor delineating the cropping seasons. With low photoperiod sensitive varieties, mungbean can be grown in any month of the year, if moisture needs during dry periods are supplied by residual moisture or by irrigation. In the development of a relay cropping system, the objective is to provide maximum production per unit of land area per year (Saxena and Yadav, 1975; Mahapatra et al., 1975; Sandhu, Gill, and Brar, 1976; PCARR, 1977). Crops are planted in quick susccession, sometimes growing as many as three or four crops per year. If a legume crop included in the rotation is well nodulated, the nitrogen fertilizer requirement for the primary crop may be partially met from this source. In the temperate climates, the cropping season is determined by the temperature and the production season for mungbean is limited to the frost-free period.

With *intercropping*, crops that differ in height, growth habit, canopy structure, and growth duration are interplanted, so that the crops occupy the land at the same time. The crops are usually planted in an alternate row pattern to facilitate planting and harvesting. Mungbean may be interplanted with sugarcane (Dayanand and Goswami, 1976); maize (Syarifuddin et al., 1974; De, Gupta et al., 1978); sorghum or pearl millet (Saraf and De, 1975; De, Gupta et al., 1978); cotton (Varma and Kanke, 1969; S. Singh, Singh, and Tomar, 1973); jute (Patel and Mitra, 1977); pigeon pea (Saraf, Singh, and Ahlawat, 1975; Kaul, Sekhon, and Dahiya, 1975); sesamum (P. P. Singh, Nema, and Kaushal, 1972); or sunflower (Campos and Macasco, 1976).

Mungbean and sugarcane is a favorable combination for intercropping. Sugarcane normally planted with 1 m row spacing will require about 60 days before developing a dense canopy or becoming highly competitive with the mungbean for soil nutrients or moisture. An early variety of mungbean interplanted between the rows of sugarcane may be harvested in 60 to 70 days without adverse effect on yield of the sugarcane which requires a much longer period before harvest. Combinations with nonlegumes that develop an early canopy, or that quickly become competitive for soil nutrients or moisture, would be less favorable than the sugarcane-mungbean combination. When seeded in alternate rows to reduce competition, the yield of the nonlegume is generally reduced as compared to its yield produced in a solid stand. However, the yield of the two crops may exceed that of a single crop in monoculture. The beneficial effect from interplanting is attributed to more efficient use of soil resources and solar radiation, and, perhaps, some nitrogen transfer from the legume to the nonlegume, although the latter is not well documented.

With *mixed cropping*, the seed of mungbean is mixed with that of other crops and broadcast seeded. Mixed cropping is practiced, usually, to spread the risk of weather hazards in economically underdeveloped areas. Under these conditions, yields are generally low and all cultural operations such as weeding and harvesting must be done by hand.

The cropping season and cultural practices for growing mungbean vary in different countries and climatic areas.

(a) India. Mungbean is grown in three seasons in India.

Monsoon or rainy season (August to October). In northern India, long duration varieties are grown, followed by wheat in the winter (November to April), and fallow in the summer (April to June) (R. C. Singh and Faroda, 1977).

Cool, dry season (December to February). In the East and South, mungbean is seeded after harvest of a crop of rice, maize, sorghum, or cotton, and followed with fallow in the summer. Varieties with low photoperiod sensitivity are grown.

Summer season (April to May). Short duration varieties and irrigation are required to grow mungbean in summer. Harvesting should be completed before the monsoon rains begin to prevent seed from being damaged. The practice of growing mungbean in summer is increasing. Rotations which include mungbean as a summer crop are:

Rice - wheat - mungbean,
Rice - potatoes - mungbean,
Cotton - wheat - mungbean,
Sorghum - wheat - mungbean,
Maize - potato - wheat - mungbean

(Nair and Singh, 1971; Misra, 1973; Sandhu, Gill and Brar, 1976; Sandhu et al., 1978; Sharma, Thakur, and Sharma, 1978; Paroda, Lal, and Singh, 1979). Cultivation of mungbean in rotation as a summer crop has the advantages: (*a*) land is utilized that would normally remain fallow and subject to wind erosion; (*b*) the hot dry weather is favorable for harvest and production of high quality seed, and (*c*) annual income per unit of land is increased. Although irrigation requirement during the summer season is high due to the high rate of evaporation, the growth duration of the mungbean crop is short, thus reducing the number of irrigations required.

(*b*) Thailand. In Thailand; mungbeans are grown in three cropping seasons (Nalampang, 1978).

Early season crop (April to June): Planted as early rains begin, following rice, and harvested before the heavy monsoon rains begin.

Second season crop (September to November): Planted after maize or sorghum, near the end of the rainy season. This crop produces about two-thirds of the total production in Thailand.

Late season crop (January to March): Planted after rice and grown on residual moisture. In the upper Plains this planting is delayed until March to avoid cold weather.

(*c*) Philippines. Mungbeans may be grown throughout the year. The main plantings are in November or December in rotations of rice-mungbean, or rice-mungbean-maize (Lavapiez et al., 1978), or during the hot, dry summer season (March to May) before rice (Calkins, 1978).

(*d*) Vietnam. Mungbean is grown at the beginning of the rainy season (April to May) at high elevations, and after rice (January to February) in the Delta (Thuy, 1969).

(*e*) Taiwan. Mungbean is grown during the hot, dry season (April to May) preceding the planting of rice (Calkins, 1978).

(*f*) Australia. Mungbean is planted in late December or January, after wheat or barley, and harvested in May or June before early frost (Bott and Kingston, 1976; Lawn and Russell, 1978).

(*g*) U.S.A. Mungbeans are planted in June after winter wheat and harvested in September or October, before wheat is planted, in Oklahoma and Texas.

(*h*) Peru. Mungbean is cultivated, under irrigation, from December until February, in the northwest coastal area.

Detrimental Effect of Continuous Cropping

Mungbean grown continuously on the same land may lead to soil effects injurious to succeeding mungbean crops (Ventura and Watanabe, 1978). In the Philippines, after two or three successive crops, yields were reduced, plants were stunted, some wilted and died. By the seventh cropping, few plants survived in spite of efforts to maintain soil fertility, and control insects, diseases, and nematodes. A soil borne fungus which infects mungbean roots, or produces a toxic substance inhibiting root growth was suspected as a causal agent. Similar effects from growing successive crops of mungbean were observed at AVRDC in Taiwan (Park, personal communication, 1980). A reported allelopathic effect of mungbean on rice in Thailand was not confirmed by experimental plants (Gympmantasiri et al., 1978).

Fertilization

Mungbeans are generally grown without commercial fertilizers. This reflects the image that mungbean is a low yielding crop which farmers consider uneconomical to fertilize. Generally, fertilization will not be beneficial if mungbeans are grown with deficient soil moisture, poor tillage, thin stands, or inadequate weed and pest control. It is a more common practice to provide fertilizer amendments to the primary crop in the rotation and depend upon mungbean to benefit from the residual effects after the primary crop is harvested.

The ideal fertility system is one that first corrects soil mineral deficiencies, and then replaces nutrients removed in the harvested crops. Mungbeans which produce a grain yield of 1 m.t./ha will remove from the soil approximately 39 kg/ha N, 3.4 kg/ha P, 10.3 kg/ha K, and 1.2 kg/ha Ca. The amounts of these elements removed will be increased if in addition the plant residues are removed and not returned to the soil. Except for nitrogen, which can be supplied by nitrogen fixing activity of appropriate soil rhizobia, the elements need to be replaced to avoid depletion of the soil mineral storehouse. The best guide to fertilizer needs for a particular field is a soil test. In the U.S.A., soybean yields have shown a consistent relationship with natural fertility, as measured by soil tests for P and K, and pH (deMooy, Pesek, and Spaldon, 1973). A similar relationship may be expected with mungbean. In the absence of a soil test, results from experimental trails in similar soils and environments, results of fertilization of adjacent farmer's fields, and observations of the thriftiness and productivity of plants growing in the field, may serve as rough guides to fertilizer needs.

Nitrogen fertilization tends to depress rhizobial activity and nitrogen fixation in legumes. However, with mungbeans, many research reports show that a small amount of nitrogen fertilizer as a starter is beneficial (Moolani and Jana, 1965; Tucker and Matlock, 1969; K. K. Singh et al., 1975; T. Singh, Agarwal, and Singh, 1975; Sandhu et al., 1978; C. Singh and Yadav, 1978; PCARR, 1977; Nalampang, 1978; and Park, 1978A). This is due to the time required for nodules to develop on young plants, and to the slow growth of the mungbean plant the first few weeks following emergence as reported by Kuo, Wang et al. (1978). For nitrogen fixation, a strain of *Rhizobium* that is effective on mungbean must be present in the root zone.

Most soils on which mungbean is grown are deficient in available phosphorus. Mungbean responds to phosphate fertilization in a variety of soil types and climatic conditions. Favorable responses have been reported from Australia (Doherty, 1963); Bangladesh (Islam, 1978); India, (Deshpande and Bathkal, 1965; Sreenivas, Upadhyay, and Warokar, 1968; Prasad, Bhendia, and Bains, 1968; Mandloi and Tiwari, 1971; K. K. Singh et al., 1975; T. Singh et al., 1975; Panwar, Singh, and Misra, 1976; Das and Patra, 1977; and others); Malaysia (Abubaker et al., 1978); Philippines (PCARR, 1977); Thailand (Nalampang, 1974 and 1978); U.S.A. (Tucker and Matlock, 1969); and Vietnam (Thuy, 1969). Although amounts vary, recommended applications of 40 to 80 kg/ha P_2O_5 are most common. Without adequate phosphate fertilization, rhizobial activity and nitrogen fixation will be depressed also.

Potassium fertilization of mungbean has received little attention in the tropics suggesting that potassium deficiency is not generally a problem. Tucker and Matlock (1969) reported a slight but nonsignificant response to potassium fertilization in Oklahoma, U.S.A. Legumes generally respond favorably to applications of Ca on acid soils. Liming is recommended for mungbean in the Philippines on soils with a pH below 6.5 (PCARR, 1977). There has been little research with micronutrients on mungbean. Application of sulfur corrected a chlorotic condition caused by inactivation of Fe and increased yield in mungbeans on a calcareous soil in India (Mehta and Singh, 1979). Sulfur, in combination with nitrogen and phosphorus increased protein and the sulfur bearing amino acids, methionine, cystine, and cysteine, in mungbean in India (Arora and Luthra, 1972).

Most fertility experiments with mungbean report yield response, but few examine the economics of fertilization. A net profit of three rupees for each rupee invested was reported by Choudhry and Bhatia (1971) in India. C. Singh and Yadav (1978) reported a favorable cost-benefit ratio when 30 to 40 kg/ha P_2O_5 were applied to mungbean. Panwar, Pandey, and Singh (1978), using 1978 prices, calculated the economic optimum rate for application of phosphorus to be 48.2 kg/ha P_2O_5. Tucker and Matlock (1969) reported a profitable return with 80 kg/ha P_2O_5; 45 kg/ha of N did not give a profitable return. The economics of fertilizing mungbean needs continuing study in view of progressively higher fertilizer costs. The largest yield response will be obtained when all essential elements are in correct balance and good cultural practices are used. Fertilization of mungbean will not be profitable if stands are poor, weeds uncontrolled, and the crop subjected to severe drought stress.

Seedbed Preparation

The seedbed for mungbean should be well pulverized and mellow, so that the seed comes into close contact with the soil, and moisture should be available for rapid seed germination. Poor seedbed preparation leads to reduced or uneven germination, slow seedling growth, and increased weed competition. Soils that are dry following harvest of a monsoon crop of rice or maize are often in poor physical condition making preparation of the seedbed difficult. Under these conditions seedbeds are often cloddy and poorly prepared, resulting in poor stands. Tillage equipment used for seedbed preparation varies from hand tools to mechanized machinery, according to the level of the local technology.

Seeding Methods and Rates

Mungbean is planted broadcast, in rows, or in hills. The broadcast method is widely practiced in Asian countries where mungbean follows rice and is grown at a low technology level. The investment is low as the method is time and labor saving. The soil is plowed once or twice after the rice harvest. The mungbean seeds are scattered by hand and covered with a harrow, drag, or by hand raking. Broadcast plantings require higher seeding rates than row planting and require hand weeding. The seedbed is usually less well prepared, and the seeds are covered to uneven depths, resulting in uneven stands. Fertilizer, although seldom used, may be spread ahead of plowing.

Seeding in rows permits more accurate spacing of plants than broadcasting. Weeding, cultivation, spraying, and harvesting are facilitated by planting in rows and yields are generally improved. Yields of mungbean seeded in rows in Vietnam were reported to be 600 to 1,000 kg/ha compared to 300 to 500 kg/ha for broadcast seeding (Thuy, 1969). There is a tendency to practice broadcast seeding where soil fertility and moisture are deficient, and yield potential is low, and row seeding where fertility and moisture portend a higher production potential. Spacing between rows varies from 25 to 75 cm depending on soil fertility, plant growth type, height, maturity, and distance needed to accomodate cultivation, spraying, and harvesting. In India, 25 to 30 cm row spacings are recommended (Sharma, 1972; Sandhu, Brar et al., 1978; Sharma and Bhatnagar, 1978; and Paroda, Lal, and Singh, 1979). For the International Mungbean Nurseries, Park (1978B) recommends 40 cm row spacing in the dry season and 50 cm in the wet season. Row spacings of 50 to 75 cm are recommended in the Philippines (PCARR, 1977) and the U.S.A. (USDA, 1975).

The seeding rate depends upon the plant population desired. Not many studies have been directed toward finding the optimum plant population under particular environmental conditions. MacKenzie, Chen et al. (1975) grew mungbeans in Taiwan over a range of 10,000 to 800,000 plants/ha. Yields began to plateau between 100,000 and 200,000 plants/ha and reached a maximum at 400,000 plants/ha. As populations were increased, plant height increased, pods per plant decreased, but seed weight remained relatively constant. In the Philippines, populations of 300,000 to

400,000 plants/ha are recommended. In India, Rathi and Verma (1974) suggest that each plant be given an area of 675 to 300 cm^2 (150,000 to 330,000 plants/ha). Row spacing, spacing of plants within the row, and seed size, all affect the plant population. Combinations of plant and row spacing required to give plant populations of 200,000, 300,000, and 400,000 plants/ha with two seed sizes are given in Table 6. Seeding rates are based on 100% seed germination, with zero mortality of seedling plants, so adjustment of rate upward of 10% to 25% is required, depending upon seed germination, soil moisture and physical conditions, and other factors that may adversely affect stand establishment.

Table 6. Row and Plant Spacings and Seeding Rates Required for Plant Populations of 200- to 400,000 Plants/Hectare.

Desired Plant Population	Row Spacing	Plant Spacing Within Row	Seeding Rate[a] for Seeds with 1000-Seed Weight of: 75 g	50 g
Plants/ha	cm	cm	kg/ha	kg/ha
200,000	25	20.0	15	10
	50	10.0	15	10
	75	6.7	15	10
300,000	25	13.3	22.5	15
	50	6.7	22.5	15
	75	4.4	22.5	15
400,000	25	10.0	30	20
	50	5.0	30	20
	75	3.3	30	20

[a]Assuming 100% germination and zero seedling mortality.

In northern Thailand, mungbean is seeded in hills on seedbeds previously used to grow garlic or other vegetables. Spacing of hills vary, but a 50 x 50 cm spacing with 6 to 7 seeds/hill is common (Gympmantasiri et al., 1978). In the Philippines, hills are spaced 50 cm between rows and 25 to 30 cm within rows, with 2 to 4 seeds planted per hill (Mamicpic and Navarro, 1969). The hill method requires hand planting and is more laborious than seeding in rows.

Inoculation of Seed

Rhizobium inoculation of mungbean should be practiced if mungbean has not been grown on the land previously, or if there is reason to suspect that the soil rhizobia is inadequate to promote effective nodulation. Because the cowpea-type rhizobia is widely disseminated in tropical areas, some nodulation will occur in most fields regardless of whether or not the seed has been inoculated.

If mungbean seed is inoculated, the following precautions should be exercised:

a. Use a strain of bacteria that will nodulate mungbean effectively.

b. Use fresh inoculum that has been stored in a cool, dry place.

c. Mix well so that several thousand bacteria comes into contact with every mungbean seed.

d. Plant the same day; do not expose inoculated seeds to sunlight, high temperatures, or drying winds.

e. Plant inoculated seed in moist soil and cover immediately.

Date of Seeding

The date of seeding will vary with climatic patterns in the different ecological areas where mungbean is grown. The cropping seasons for mungbean in different countries have already been discussed. Some factors that influence strongly the date of seeding are temperature, soil moisture, projected rainfall patterns, photoperiod, sequence in the rotation, and seasonal occurrence of disease and insect pests. Warm soil and air temperatures are required for quick germination and rapid seedling growth. Mungbean grown at the end of the monsoon season needs to be seeded quickly after the harvest of the monsoon crop in order to make maximum utilization of the residual soil moisture supply. In some areas, the date of seeding may be altered in order to avoid maximum disease and insect injury. In India, the vector spreading yellow mosaic virus is least prevalent during summer, so virus damage is less severe on mungbean planted during the summer season. In Thailand, beanfly damage may be reduced by planting in the summer season when the beanfly population is smallest.

Water Management

Irrigation is essential for production of mungbean during the hot, dry summer season, and may be beneficial for rainfed mungbean during periods of drought. A presoaking prior to planting may be beneficial on dry soils to prepare the seedbed. This is followed by four to eight furrow irrigations throughout the growing season as needed to avoid severe drought stress. Drought stress is most harmful to seed yields if it occurs just prior to flowering and during the pod-filling stage (Chiang and Hubbell, 1978). Singh and Bhardwaj (1975), in India, propose that available soil moisture be maintained at 20% before flowering and 40% after flowering. Furrow irrigation is preferable to sprinkler irrigation as there is less lodging and damage to the mungbean plants. Wet lands need to be drained since mungbean yields poorly in wet or waterlogged soils.

Cultivation and Weed Control

Timely control of weeds is essential for high yields in mungbean. Weeds compete with the mungbean plant for soil moisture, mineral nutrients, and light, and hinder harvest operations. Uncontrolled, weeds may reduce yields by as much as 90% (Madrid and Vega, 1971). The first step in weed control is a well prepared seedbed in which many of the weed seeds have germinated and the weed seedling plants destroyed. The mungbean plant is not strongly competitive with weeds during its early growth (Moody, 1978), but the competitive position will be improved with high plant populations and inoculation with efficient rhizobial strains.

(a) Cultivation. Weed competition may be reduced by hand weeding, hoeing, machine cultivation, and application of herbicides. Hand weeding may be injurious if it loosens or uproots the mungbean plant in the process. Care needs to be exercised in hoeing to prevent injury to the mungbean root system. The first 5- to 6-week period after seeding is the critical time to keep mungbean weedfree according to experiments in the Philippines (Madrid and Vega, 1971; Moody, 1973), Tanzania (Enyi, 1973), and India (Rethinam et al., 1976A; M. Singh, Kolar, and Sandhu, 1978). Row or hill-planting facilitates hand weeding and hoeing, and is essential for machine cultivation. Machine cultivation should be shallow to avoid injury to the root system. Weeds may be shaded out by the early development of a dense plant canopy. The plant canopy develops more quickly if the mungbeans are planted in narrow rows and with high plant populations.

(b) Herbicides. Herbicides, either alone or in combination with cultivation, may be used to control weeds in mungbean. Herbicides differ in the effectiveness with which they control different weed species, so accurate identification of the weed species to be controlled is needed. The effectiveness of the herbicide is affected by the time, rate, and method of application; by temperature, and other environmental conditions at the time of application; and by soil texture. Higher rates of herbicides are normally required on organic or clay soils, due to adsorption on the colloid particles, and lower rates on coarse textured or sandy soils. Seedling weeds are more easily killed than mature weeds, and their destruction results in less competition to the mungbean plant than if the weeds are permitted to mature. The rate of herbicide application should be adjusted to give maximum weed control without significant injury to the mungbean plant. Application rates in excess of those needed for effective control of weeds cause unnecessary production costs and also increases the injury to the mungbean plant.

The method of application is determined by the specific herbicide being used and the type of weed to be controlled. Herbicides that volatilize readily, or which decompose upon exposure to sunlight, are applied before planting and mixed with the upper 1- to 2-inches of soil, but kept above the germinating seed. Known as *preplant* herbicides, they are used primarily to kill grass-type weeks but may also be effective on some broadleaf weeds. *Preemergence* herbicides, used to kill broadleaf weeds and some weed grasses not controlled by preplant herbicide applications, are sprayed onto the weed plants. If the herbicide is harmful to the mungbean plant, spot applications may be made to the weeds, about two to three weeks after the emergence of the mungbean crop. Before applying a herbicide, the label should be examined carefully to learn which weeds it will control, the crops on which it can be applied safely, the method and rate of application, and special precautions to be taken with its use. Herbicides are generally applied in a liquid form with a sprayer. Granular herbicides are more expensive, less effective, and would rarely be used on grain legumes such as mungbean.

Increase in grain yields of mungbean from weed control have been reported from India by P. Singh, Choubey, and Kushwaha (1971), Saroha and Gupta (1972), Retinahm et al. (1974), Thangaraj and Soundarapandian (1974), Rethinam, Sankaran, and Sankaran (1976), Rethinam et al. (1976B), Patro and Tosh (1977), and with blackgram by Ali et al. (1974). The increase in grain yield from hand weeding over unweeded averaged 82% in five experiments. Increases from use of herbicides over unweeded checks were as follows: trifluralin, 51% (1 experiment); 2,4DB, 20% (1 experiment); nitrofen, 92% (5 experiments); alachlor, 96% (5 experiments); terbutryn, 185% (2 experiments); and dichlormate, 83% (2 experiments). A partial list of herbicides for weed control in mungbean is given in Table 7. In the Philippines, butralin and chlorthal are used for preemergence application to control annual grasses and broadleaf weeds, and bentazon for post-emergence application to certain broadleaf weeds and sedges (PCARR, 1977). In Australia, trifluralin is used as a preemergence spray (Lawn and Russell, 1978). In Oklahoma, U.S.A., trifluralin and profluralin are used for preplant and DCPA for preemergence application to mungbean (Greer, 1980). At AVRDC, butralin controlled both grass and broadleaf weeds with minimum damage to the mungbean (AVRDC, 1978C).

Currently, the formulation and marketing of herbicides is a dynamic field of activity. New, improved herbicides may be expected to replace those listed here, or currently used herbicides may be removed from the market if they are found to be unsatisfactory. The performance of a herbicide is affected by many environmental and other factors, and specific herbicides should be tested thoroughly in an area before their use is recommended. Also, the effects of a particular herbicide on the rhizobial strains in the soil that are efficient in nodulating mungbean need careful study before the herbicide is used to control weeds in mungbean.

Use of herbicides to control weeds will be practiced most widely in developed countries where mungbean is grown in large fields; labor costs are high; and herbicides, spray equipment, and technical assistance are readily available. Rate of application and incorporation of preplant herbicides will be more accurate where machine rather than hand application procedures are used. Where mungbean is grown in tropical areas with a low

Table 7. Partial List of Herbicides for Weed Control in Mungbean.[a]

Common Name	Trade Name[b]	Method of Application	Types of Weeds Controlled
Alachlor	Lasso	Preplant or preemergence	Annual grasses, nutsedge, and some broadleafs
Bentazon	Basagram	Postemergence	Broadleafs
Butralin	Amex 820	Preplant	Annual grasses and some broadleafs
Chloramben	Amiben	Preplant or preemergence	Annual grasses and many broadleafs
Chlorthal, DCPA	Dacthal	Preemergence	Annual grasses and a few broadleafs
Diphenamid	Dymid	Preplant or preemergence	Annual grasses and some broadleafs
Nitrofen	TOK	pre- or postemergence	Annual grasses and some broadleafs
Trifluralin	Treflan	Preplant	Annual grasses and some broadleafs
Vernolate	Vernam	Preplant	Annual grasses, nutsedge, and some broadleafs
2, 4-DB	Butyrac	Postemergence	Broadleafs

[a]Regulations regarding use of herbicides may vary from country to country. Before using a herbicide on mungbean, local regulations should be examined to insure that use of the herbicide is not prohibited. The label on the herbicide should be examined carefully for crop on which use is safely recommended by the manufacturer, for particular weed species that may be controlled, and for precautions to be taken in handling and use of the herbicide.

[b]Trade names are used in this publication to provide specific information. Mention of a trade name does not constitute a warranty of the product by the University of Puerto Rico, the U.S. Agency for International Development, or the authors, or an endorsement over other products not mentioned.

level of technology, herbicides, even if available, may be too costly to use. Local studies on the economics of their use by the subsistance farmer are needed.

Harvesting and Threshing

In tropical countries, most mungbeans are harvested by hand picking ripe pods. The pods are ripe and ready to pick when they turn black or brown. This occurs about three weeks after the flower opens. The growth habit of the mungbean plant is indeterminate; new flowers open and pods ripen over a period of several weeks. The mungbean plant does not senesce, the process of reaching physiological maturity followed by shedding of leaves uniformly from the plant. It is common to have green leaves, open flowers, green pods, and ripe pods on a mungbean plant at the same time. Ripe pods remaining on the plant for long periods may shatter. During long periods of precipitation and high humidity, the ripe seeds may mold or even sprout in the pod. To avoid loss or damage to seeds, in many areas the mature pods are picked as they ripen. Long-season varieties require three to five pickings. New, short-season varieties may need only two or three pickings.

Hand picking is laborous and the most expensive single operation in mungbean production. It amounts to 25 to 30% of the total production cost, and 40 to 50% of the total labor cost (Calkins, 1978). At AVRDC, in Taiwan, the fall crop was harvested more efficiently than the spring crop because the fall harvest was completed with two pickings, vs. three to five pickings in the spring. In the fall, laborers averaged 3 kg/hr per person, in the spring they only averaged 1.9 kg/hr (AVRDC, 1978A). Varieties differed in the efficiency with which they could be harvested. In the fall harvest, laborers could harvest 4.6 kg/ha of the variety PHLV18 but only 2.2 kg/hr of the variety ML-3. PHLV18 produces long pods and large seeds, with most of the pods borne in the top of the plant where they are easily accessible. ML-3 produces short pods and small seeds, with the pods scattered uniformly over the plant, requiring additional time for picking.

Pods picked by hand are dried in the sun and threshed by trampling; or they are placed in a jute bag and beaten out with a stick. Seed is separated from the hulls by screening and by winnowing. Seed needs to be dried to 12% moisture or below before storing.

Efforts are being made to mechanize the harvesting operation to reduce labor costs. The entire plant may be harvested with a sickle and seeds trampled out (Islam, 1978), or cut and threshed on small threshers such as used in Southeast Asia for rice and wheat. Cutting and threshing increased labor efficiency tenfold over hand picking at AVRDC (AVRDC, 1978B). A thresher with a rasping bar is superior to one with a spike tooth cylinder as fewer seeds will be cracked and damaged. In the U.S.A. and Australia, mungbean is harvested with a c. . ine-thresher, either by cutting directly or by picking up harvested plants from a windrow. In harvesting with a combine, ground speed should be kept slow to avoid shattering, and cylinder speed slowed down to prevent cracking or injuring the seed coat and embryo. Otherwise, seed germination will be impaired.

Seeds should contain no more than 12 to 13% moisture at time of combining if they are to be stored without drying. Combining below 10% moisture may result in excessive cracking or seedcoat injury. Uneven ripening of mungbean pods and ripening of pods before all of the leaves are dry causes problems in combining. Delaying the combining until all pods are ripe will cause loss from shattering of early ripening pods. Generally, mungbean may be combined when about 75% of the pods are ripe. Combining at this stage results in some green leaves, broken green stems, and immature seeds being included with the grain. This material will increase the moisture content of the seed unless removed. Otherwise, the grain heats rapidly and the seeds lose viability making them unfit for sprouting. Artificial heat may be employed to aid in drying, but drying at too high a temperature will reduce germination. The maximum temperature for drying soybeans to be used for seed is 43°C, and this would seem to be a safe maximum temperature for drying mungbean. Dried seed needs to be handled carefully to avoid cracking.

Defoliation

Dessicants may be applied to mungbean before combine harvesting to kill leaves and reduce the green foreign material in the combine harvested seed. Other benefits are earlier harvest with less loss from shattering and faster combine ground speed. In Australia, the dessicant, paraquat, applied when pods were 75 to 100% mature did not significantly reduce yields (Beech and Wood, 1978). Use of a dessicant increases the production cost. The label of the dessicant should be examined carefully to determine whether or not it is approved for use on mungbean.

Storage

For storage, mungbean should be dried to a moisture content of 10 to 12%, have foreign material removed, be kept in a cool dry place, and protected from insects and rodents. Mungbean has a long germination life if properly stored. Deterioration in storage is primarily due to molds and insects. Both are favored by high moisture and warm temperatures. Good ventilation of storage areas to dissipate accumulated heat or moisture is an essential safeguard. Forced air drying of seed storage in bins will aid in keeping the grain in good condition.

The most common and destructive storage pests of mungbean are the bean weevils, *Callosobruchus chinensis* L. and *C. maculatus* F. (S. N. Singh and Lal, 1975). Infested grain may be completely destroyed by these insects. Control begins by thoroughly cleaning all storage areas, bins, sacks, or other containers of insects or remnents of infested grain. Bins, sacks, or containers should be fumigated with aluminum phosphine or sprayed with malathion. Care should be taken to prevent bringing insects or insect eggs in with grain. Drying grain by exposure to hot summer sun will destroy many of the insects.

VIII GENETICS

Genetic studies of the mungbean have been conducted largely in India where the crop is grown most extensively. Even so, the studies have been limited, reflecting the lesser importance of mungbean as a crop, in comparison with the cereals, or soybeans. The small size of the chromosomes also discourages cytological studies, or makes them difficult at best.

Cytology

Mungbean has the chromosome number $2n = 2x = 22$ (Karpechenko, 1925). The chromosomes vary in length from 28.1 to 73.3 μ and may be identified at pachytene on the basis of chromosome arm ratios and relative lengths (Krishnan and De, 1965). Krishnan and De grouped the somatic chromosomes into six types on the basis of length, position of the centromere, and presence or absence of secondary constrictions. Two nucleolar chromosomes differ in relative length and position of secondary constrictions at pachytene and somatic metaphase stages. In a comparison of karyotypes in three wild types and two cultivated varieties, the wild types had shorter somatic chromosomes than the cultivated varieties (Shrivastava, Singh, and Sharma, 1973). Bhatnagar et al. (1974) compared the chromosome complements of several related species and suggested a karotype formula for mungbean, $4L^{sm} + 4M^{sm} + 3M^{m}$ (where L = long, 2.7 to 3.5 μ; M = medium, 1.9 to 2.6 μ; ^{sm} = submedian centromere; and ^{m} = median centromere).

Interspecific Hybridization

Mungbean (*Vigna radiata* (L.) Wilczek) is closely related to blackgram (*V. mungo* (L.) Hepper), rice bean (*V. umbellata* (Thumb.) Ohwi and Ohashi), adzuki bean (*V. angularis* (Willd.) Ohwi and Ohashi), and a wild species, *V. radiata* var. *sublobata* (Roxb.) Verdc. All of the related species, like mungbean, have chromosome numbers of $2n = 2x = 22$. Genome designations AA have been proposed for *V. radiata* and *V. mungo* (Dana, 1966A) and A_1A_1 for *V. umbellata* (Dana, 1966B). Blackgram, ricebean, and adzuki bean have characteristics that would be useful in mungbean if they could be transferred through breeding procedures. So far, this has not been accomplished.

The interspecific cross, mungbean x blackgram, has been made by Sen and Ghosh (1960A), Dana (1966A), De and Krishnan (1966), Ahn and Hartmann (1978B), and at AVRDC (AVRDC, 1979). Blackgram has resistance to the disease pathogens causing *Cercospora* leaf spot, mungbean scab, and yellow mosaic virus; resistance to cowpea weevil; and high methionine content in the seed protein. The cross is successful only if mungbean is used as the female parent. Compatibility, as measured by percent hybrid seeds obtained, germination of hybrid seeds, and survival of F_1 plants, varies with the parent genotypes (AVRDC, 1979). Compatibility is improved if two mungbean varieties are crossed and the F_1 crossed as female with blackgram, but germination of F_2 seeds is still irregular (Ahn and Hartman, 1978B). Fertility was partially restored by converting the F_1 into an amphidiploid (U. Singh and Singh, 1975).

The rice bean is resistant to the pathogens causing *Cercospora* leaf spot and powdery mildew and to the beanfly. The interspecific cross, mungbean x rice bean, has been made by Dana (1966B), Sawa (1974), Ahn and Hartmann (1978B), and at AVRDC (AVRDC, 1979). Some viable F_1 seeds are obtained if mungbean is used as the female parent, but F_1 plants are sterile. The hybrid sterility is partially overcome by doubling the chromosomes and producing an amphidiploid.

The interspecific cross, mungbean x adzuki bean, has been reported by Sawa (1973) and Ahn and Hartmann (1978A and 1978B). In both attempts, the cross produced a few seeds which grew slowly and then aborted shortly after pollination. By culturing F_1 embryos, a few seedling hybrid plants were obtained which reached maturity but produced no seeds. The low level of chromosome pairing suggests that the two species are distantly related.

A cross of mungbean x *V. radiata* var. *sublobata*, the wild relative, was reported to be successful only when mungbean was used as the female parent (Ahuja and Singh, 1977), but reciprocal crosses were successful at AVRDC (AVRDC, 1979). Ahuja and Singh carried the cross through the F_4 generation, observing a wide range in segregation. A cross between mungbean and an unidentified tetraploid *Phaseolus* species produced one F_1 plant that reached maturity but did not produce seeds (Dana, 1965). A cross of autotetraploid mungbean as female with the unidentified tetraploid *Phaseolus* produced seeds, but the hybrid plants failed to produce seeds except when backcrossed as female to the autotetraploid mungbean (Krishnan and De, 1968). Hybrid plants from the cross mungbean x *V. trilobata* were sterile; when the chromosomes were doubled, fertile amphidiploids were obtained (Dana, 1966C and 1966D).

Genetic Variability in *Vigna radiata*

Divergent views have been expressed about the range of genetic variability in the mungbean. Mungbean breeders in various countries initiated breeding programs with small indigenous collections of related germplasm. Lack of progress in these breeding programs often led to pessimistic expressions regarding genetic variability in the species. For these programs to have made breeding progress, infusions of germplasm from a broader geographic and genetic base would have been needed. A more optimistic viewpoint on breadth of the genetic variability has been reported in germplasm evaluation studies reported by Bhargava et al. (1966), Chowdhury et al. (1968), Gupta and Singh (1970), Yohe and Poehlman (1972), Malhotra, Singh, and Singh (1974A), AVRDC (1979), and others. At AVRDC, 68 promising lines were evaluated for 29 quantitatively measured agronomic characters such as yield, pods/plant, seeds/pod, 1,000 seed weight, pod length, and others (AVRDC, 1979). Significant differences among varieties were recorded for all characters studied, suggesting that genetic variability adequate for varietal improvement in these characteristics was available among the accessions evaluated. Since unadapted strains are generally included in these studies, it is relatively common to observe a wide variation in expression of quantitatively measured plant characters. For this reason some of the reports may be overly optimistic about the useful range of variability, especially where only a small number of accessions were examined. With quantitative characters, the breeder needs to look for variability that will contribute to significant improvements over adapted varieties.

Searches to find specific genes to correct deficiencies in adapted varieties are often less rewarding. The largest collection of mungbean germplasm, about 5,000 accessions, is maintained at the Asian Vegetable Research and Development Center (AVRDC), Shanhua, Taiwan. But only a small number of accessions from the collection have been identified with resistance genes to important disease pathogens or insects. For example, resistance for *Cercospora* leaf spot was identified only in 6 accessions; resistance for powdery mildew in 15 accessions; resistance for mungbean mottle mosaic in 7 accessions; resistance for damping-off and a root disease complex, none; resistance for rootknot nematode in 4 accessions; resistance for beanfly in 3 accessions; resistance for pod borer, none highly resistant; resistance for bruchids in 2 accessions (AVRDC, 1979). It is probably that some of the accessions resistant to the particular pest are related, hence the actual number of genes for resistance with which the breeder has to work may be even fewer than indicated by the number of resistant lines identified.

The genotype x environment interactions are important in evaluating strains for potential yielding ability. In any particular trial, adverse environmental response to photoperiod, length of growing season, presence of local diseases, etc., can seriously impair the yield of a strain which may have high yield potential in other environments (Joshi, 1969). This was demonstrated forcefully at Ludhiana, Punjab, in the 4th International Mungbean Nursery, where the only strains that produced economic yields were those with resistance to the mungbean yellow mosaic virus (Poehlman et al., 1976). Another problem with evaluation of germplasm collections is that genetic diversity is no longer assured by diversity in the geographic origin of an accession. Exchanges in germplasm among mungbean breeders has resulted in the same strain, or slight variations of it, being grown in many different geographic areas. The germplasm collection at AVRDC has numerous duplications because the same strain was submitted to it by breeders from more than one production area.

The importance of developing and maintaining diverse germplasm collections is discussed later in this report.

Qualitative Inheritance in Mungbean

Genetic studies in mungbean were begun in India by Bose (Bose, 1939). Presently, 45 genes have been identified (Fery, 1980). Fery, in his "Genetics of *Vigna*" constructed a set of gene nomenclature rules for the genus *Vigna*, adapted from nomenclature rules developed for Cucurbitaceae, and proposed a preferred gene symbol for each of the 45 *Vigna radiata* genes.

Twenty-seven of the 45 genes reported relate to color of mungbean plant structures. The color markings include epicotyl color (Sen and Ghosh, 1959); flower color (Bose, 1939; van Rheenan, 1965; Murty and Patel, 1972-73); foliage color (Pathak and Singh, 1963); fruit color (Sen and Ghosh, 1959); pubescence color (Sen and Ghosh, 1959); hypocotyl color (Sen and Ghosh, 1959; van Rheenan, 1965; Swindell and Poehlman, 1978); pod color (Sen and Ghosh, 1959; Pathak and Singh, 1963); pod suture color (Bose, 1939; Pathak and Singh, 1963; Murty and Patel, 1972-73); and seed coat color (Bose, 1939; Sen and Ghosh, 1959; van Rheenan, 1965; M. K. Singh, 1973). Inheritance studies relating to color of plant structures are often difficult to interpret because they involve shades of color which were named without reference to standard color charts, hence the nomenclature differs with different research workers. This could lead to duplicate names for particular genes.

Inheritance of seed coat texture and color presents a special problem. Dull seed coat is reported to be dominant to shiny by Bose (1939), van Rheenan (1965), K. B. Singh and J. K. Singh (1970), and Murty and Patel (1972, 1972-73). Watt, Poehlman, and Cumbie (1977) reported that dull seeds are covered with a texture layer originating from the inner pod membrane, which when removed exposes a shiny seed coat underneath. The membrane may be pigmented, brown or black, or it may be translucid through which the color of the seed coat underneath is visible. With this information, earlier inheritance studies on seed color need to be reevaluated to identify whether the color markings reported were present in the seed testa or in a rough outer membrane layer. Seed color caused by pigmentation in the outer membrane layer would be dependent upon the layer being present which is inherited independently from seed testa color.

Photoperiod insensitivity was reported to be dominant over photoperiod sensitivity by Verma (1971) and Tiwari and Ramanujam (1976B). Neither experiment was conducted under co trolled photoperiods, so it is difficult to know whether the authors were uring photoperiod response or earliness, a characteristic which is frequently dominant. Swindell and Poehlman (1978), working in a series of controlled photoperiods, identified a dominant or partially dominant gene for photoperiod sensitivity in mungbean accession PI180311 which was expressed in 16- or 14-hour but not in 12-hour photoperiods. In absence of the effect of the gene, dominance x dominance epistatic effects from background genes were indicated as governing days to flower.

In addition to the above, genes have been reported for resistance to pathogens causing bacterial leaf spot, *Cercospora* leaf spot, mungbean yellow mosaic virus (Thakur et al., 1977B), and cucumber mosaic virus (Sittiyos et al., 1979). Genes have also been identified governing flowering (Tiwari and Ramanujam, 1976B); presence of pubescence (Murty and Patel, 1972-73); leaf margin shape (D. Singh and Mehta, 1953; Sen and Ghosh, 1959; Pokle, 1972); plant growth habit (Sen and Ghosh, 1959; Pathak and Singh, 1963); and pod clusters (T. P. Singh and K. B. Singh, 1970).

Genes identified earlier in *Vigna radiata* were contained in a wide spectrum of parent materials. It is probable that it would no longer be possible to recover all of the genes identified.

Quantitative Inheritance in Mungbean

Many characters important in breeding are inherited in a quantitative manner. Yield and quality are typical examples. Improvement in the expression of a quantitative character is dependent upon having a range of genetic variability for the character under consideration, and an understanding of the mode of gene action so that the most efficient breeding procedure may be utilized.

(*a*) Association of Plant Characters and Yield. After genetic variability for plant characters has been identified, the breeder is confronted with sorting out the combination of characteristics that may be combined to give the highest yield potential. One tool that is employed to assist in identifying the related characteristics is correlation analyses Correlation coefficients for the yield components--pods/plant, seeds/pod, and seed weight--with yield in mungbean are reported in Table 8. The yield component pods/plant was closely associated with yield in all experiments. A low pod production may be partially offset by more seeds/pod and heavier seeds, but the relationship of the latter yield components with yield was less consistant. Plant size, as measured by height and number of branches, was also highly correlated with seed yield (Gupta and Singh, 1969; Malhotra, Singh, and Singh, 1974; Yohe and Poehlman, 1975). While abundant pod production is necessary for high seed yield, large plants provide the sites on which to hang the pods. Maladies such as disease have an adverse effect on yield. A negative correlation of virus injury with yield ($\underline{r}$ = 0.630*) was reported by Yohe and Poehlman (1975).

Table 8. Correlation Coefficients for Grain Yield with Yield Components in Mungbean.

Pods/ Plant	Seeds/ Pod	Seed Weight	Reference
	-.384	.154	Gupta and Singh (1969)[a]
.851**	.444*	.160	Singh and Malhotra (1970B)[b]
.950**	.980**	-.210	Joshi and Kabaria (1972,[a]
.997	.073	.929	Chandel, Joshi, and Pant (1973)[a,c]
.858**	.292	.236	T. P. Singh and K. B. Singh (1973A)[b,d]
.951**	.690**	.486**	Malhotra, Singh, and Singh (1974A)[b]
.878*	.601*	.764*	Yohe and Poehlman (1975)[b]
.440**	.400	.690**	Bhaumik and Jha (1976)[b]

[a]Genotypic correlations.

[b]Phenotypic correlations.

[c]Significance not reported.

[d]Average of six crosses.

(*b*) Heritability of Yield and Associated Characters

Partitioning of phenotypic variance into genetic and environmental cuases is done through heritability analyses. In broad sense heritability estimates, the genetic portion contains variance due to all genetic influences. Narrow sense heritability estimates include only that portion of the variance due to additive gene effects and hence responsive to phenotypic selection. Heritability estimates of yield and associated parameters in mungbean have been reported by Gupta and Singh (1969), Empig et al. (1970), K. B. Singh and Malhotra (1970A), Tomar, Singh and Sharma (1972), Joshi and Kabari (1973), Verraswamy et al. (1973), and others. Fery (1980) has summarized the broad sense heritability estimates for various traits including the yield parameters. Wide variations in heritability estimates have been reported; 22 to 90% for number pods per plant, 6 to 83% for seeds per pod and 51 to 99% for seed weight. The variations are a result of (*a*) each heritability estimate being calculated in and applicable to a particular environment only, and (*b*) types of gene action differing with different parent varieties. In most of the experiments, heritability estimates reported for yield and the yield components, pods per plant and seeds per pod, are lower than for the yield component, seed weight. Plant height and days to flowering generally have high heritability values in most environments.

(*c*) Combining Ability, Types of Gene Action, and Path Coefficient Analyses of Yield and Its Components. The inheritance of yield and its components in mungbean has been studied for combining ability and type of gene action by the use of diallel crosses by K. B. Singh and Jain (1971A and 1971B), T. P. Singh and Singh (1971, 1972, and 1974), Yohe and Poehlman (1975), Ramanujam (1978), and Ko (1979). Overall, the combining ability studies show that genetic variability for yield and its major components is the result of both *gca* and *sca* effects, the magnitude of the effects varying with the population and the environment. Since *gca* variances were generally greater than *sca* variances, the variables were predominantly controlled by loci with additive gene effects. Thus classical breeding systems which make use of additive gene variance would be effective for genetic modification of yield and its principal components.

Yield is determined by contributions from several yield components. The direct and indirect contributions to yield of specific yield components has been measured by path coefficient analyses (K. B. Singh and Malhotra, 1970B; T. P. Singh and Singh, 1973A; Chandel, Joshi, and Pant, 1973; Giriraj and Vijayakumar, 1974; Malhotra, Singh, and Singh, 1974B; Pokle and Patil, 1975; Bhaumik and Jha, 1976; and Ko and Choe, 1976). Pods-per-plant were shown to contribute indirectly through seeds-per-pod and seed-weight. Plant height and number of baranches contributed indirectly to yield through pods-per-plant, tall plants with many branches being capable of supporting the most pods. The studies confirm the importance of a large number of pods per plant to obtain high yields, an association that was established also by correlation analyses.

Heterosis in Mungbean

Heterosis in mungbean following intervarietal crosses has been reported by Bhatnagar and Singh (1964), Misra, Sahu and Tripathy (1970), K. B. Singh and Jain (1970), Ramanujam, Taiwari, and Mehra (1974), Swindell and Poehlman (1976), and Ko (1979). Over all experiments, the increase in yield of the hybrid over the midparent ranged from 17% to 208%, and the increase of the hybrids over the high parent ranged from 1% to 188%. The hybrid was significantly higher in yield than the midparent in only 23 of 58 crosses, and significantly higher than the high parent in only 6 of 33 crosses. The low proportion of crosses with significant heterosis suggests that a large number of hybrid combinations need to be made in a mungbean improvement program in order for superior cross combinations for yield to be identified. In addition to yield, positive heterosis was reported for characteristics related to plant size, such as height, number of branches, and branch length. Heterosis was not observed or was negative for seed weight. Generally, hybrids were earlier than the midparent. Heterosis for protein content was observed, but the magnitude of the heterosis was small (T. P. Singh and Singh, 1973B). Out of 25 crosses, only 3 exhibited significant heterosis for methionine content (Tiwari and Ramanujam, 1976A). With the closed pollination system in mungbean, it is unlikely that heterosis will be exploited commercially in this crop.

Polyploidy in Mungbean

Mungbean and its close relatives are diploid species. Autopolyploidy may be induced by treating apical buds of seedling plants with colchicine. The colchicine is applied as the first pair of seedling leaves are expanding by covering the apical bud with a cotton plug soaked in a 0.2% to 0.4% colchicine solution (Kumar and Abraham, 1942A and 1942B; Sen and Murty, 1960), or by applying the colchicine in a lanolin paste. Affected plants may be mixoploid. Seeds harvested from suspected tetraploid sectors are germinated and chromosome counts made from root tip sections to verify whether or not they are tetraploid. Seedlings identified as tetraploid can then be grown to maturity.

Tetraploid plants of mungbean grow slowly, are smaller in size, have fewer branches, and flower later than diploid plants (Kumar, 1945; Sen and Murty, 1960; Sen and Ghosh, 1960B). The leaves of the tetraploids are darker green, thicker, and smaller than leaves of diploids. Flowers are conspicuously larger and tend to set fewer and heavier seeds. Genotypes differ in the performance of the tetraploids. Selection within the tetraploid progenies improved fruit setting, but not size of fruits and number of seeds per pod (Sen and Murty, 1960). The F_2 progenies of crosses among tetraploids were highly variable with some plants exceeding the corresponding diploid in yield (Sen and Ghosh, 1960B). All reciprocal crosses of tetraploids with diploids failed.

Possibilities of using tetraploids as commercial varieties do not appear promising, but they might be useful in bridging a cross with a tetraploid species. A natural tetraploid identified as *Vigna radiata* var. *glabra* has been identified. The tetraploid originated in the

Philippines, is perennial, has hypogeal germination, and is suspected of being amphidiploid in origin (Swindell, Watt and Evans, 1973). A spontaneous amphidiploid has been identified which originated as a branch of an F_1 plant of the interspecific cross, *Vigna radiata* x *V. trilobata* (formerly *Phaseolus trilobus*) (Dana, 1966C). The tetraploid segments of the branch bore seeds whereas other branches on the same plant did not.

Mutation Research in Mungbean

With the view that there is limited genetic variability in the mungbean, mutation research has been undertaken, mostly in India and Pakistan, in efforts to increase the range of variability. Because mutagen treated seeds show varying degrees of injury or sterility in the M_1 generation, studies have been conducted to evaluate the sensitivity of mungbean to mutagenic agents (Murray and Newcombe, 1970; Rajput, 1973; Yahya, Alam, and Yousouf, 1975; Khan and Hashim, 1978). Effects commonly observed in M_1 generation are reduced germination of treated seeds, reduced height of plants, reduced fertility and seed yield, and reduced nodulation (Rangasamy, Oblisami, and Krishnaswami, 1973). With mungbean, ^{60}Co gamma radiation has been used extensively as the mutagenic agent, although radiations from x-rays and neutrons, and the chemical mutagens, EMS and DMSO, have been used also. A ^{60}Co gamma radiation dose of 30 to 40 KR was effective for inducing variability (D. P. Singh, Vaidya, and Bhatt, 1979). The mutation spectrum produced by EMS or DMSO differs from the spectrum produced by radiation. Generally the effects are less harsh, producing more gene mutations and fewer chromosome aberrations (Chaturvedi and Singh, 1978).

In M_2 and subsequent generations, Santos (1969), Dahiya (1973 and 1978), Rajput (1974), Tikoo and Jain (1974), Prasad (1976), and others, reported mutations for shorter plants, earlier maturity, increased number of branches and pod clusters, higher pod set, heavier seeds, and higher protein content. Of these characters, only the increased number of pod clusters and higher pod set were correlated significantly with increases in yield (Krishnaswami, Khan, and Rangasamy, 1973).

The purpose in mutation breeding is to increase the range of variability in specific characters. Seldom will the primary mutant be as vigorous and productive as the parent variety. After a desired mutant gene is identified, then the mutant gene will need to be transferred into adapted varieties by traditional recombination breeding programs. Often the mutant is accompanied by undesirable pleiotropic effects which limits its usefulness in a breeding program.

IX BREEDING

A decade ago viable breeding programs were found only in India, the Philippines, U.S.A., and a few other countries. With the founding in 1971/72 of the Asian Vegetable Research and Development Center in Taiwan, an extensive breeding program with mungbean was organized which is now supplying breeding materials to national programs in Southeast Asia and elsewhere. The initiation of the International Mungbean Nursery in 1972 also stimulated interest and international cooperation in mungbean breeding.

Flowering and Crossing Procedures

Flowers of mungbean are borne in clusters of 10 to 20 in axillary or terminal racemes. Pollination occurs at night, beginning around 9 to 10 p.m., and is completed around midnight (Bose, 1939). Early the next morning the flowers begin to open, remain in full bloom until shortly before noon, and then begin to close and are fully closed by mid- to late-afternoon. Self-pollination is the rule and cleistogamy is common (Narasimham, 1929), but outcrossing by small pollen-carrying insects may occur. The outcrossing averages around 2 to 5% (van Rheenen, 1964; AVRDC, 1977), but will vary with the variety and the season.

Flower shedding in mungbean is common, plants producing many more flowers than set seeds. Flower shedding is increased by high temperatures and dessicating winds during the flowering period. Flower shedding averaged 60% in nine varieties in Rajasthan state in India (Bhatt, Mishra, and Chandola, 1972), and 46% in four varieties in Punjab state (Kaul, Singh, and Sekhon, 1976). Under the Punjab climatic conditions there was 38% flower shedding in blackgram and 54% in cowpea.

The crossing procedure in mungbean is not difficult, but seed set is often low due to the high amount of pod shedding following artificial cross-pollination. Crossing is accomplished by using the technique described by Buishand (1956) for beans, as modified by Boling, Sander, and Matlock (1961). Emasculation is performed by pushing one side of the standard and the corresponding wing petal outward with a dissecting needle, and removing one-half of the keel petal and the anthers with forceps, taking care not to injure the stigma. For the pollen source, mature flowers are selected in which the anthers have dehisced and covered the stigma with ripe pollen grains. The pollen covered stigma is brushed lightly across the stigma of the emasculated flower to complete the pollination. After pollination the wing and standard petal are returned to their original position, covering the pollinated stigma to prevent it from drying out. Highest pod set is obtained by emasculating in the evening with pollination the following morning (T. P. Singh and Malhotra, 1975). About 20% pod set has been normal, although 60% pod set with an average seed set of 6 seeds per pod has been reported from AVRDC (Park and Yang, 1978).

<u>Germplasm: Sources, Collections, Characterization</u>

An initial step in a breeding program is the assembly of germplasm with a wide range of genetic variability. The breeder acquires his working germplasm collection from (*a*) native or improved local varieties, (*b*) varieties and breeding lines from existing breeding programs or germplasm collections, and (*c*) closely related wild species. Local varieties, where available, are usually acquired first. Local varieties of native origin are often low in yield potential, but may possess characteristics that give stable production in the local environment. Local collections may be supplemented by varieties and breeding lines acquired from other mungbean breeders or from mungbean germplasm collections. Improved varieties, whether developed locally or acquired from elsewhere with production potential proven in local trials, generally provide the most substantively genetic materials with which to initiate a breeding program (Horst, 1961).

The generation of improved breeding materials has been augmented with establishment of the Asian Vegetable Research and Development Center, located at Shanhua, Taiwan. An extensive breeding program has been developed at AVRDC, with several hundred crosses made annually from genetically diverse parent materials. Seeds from segregating progenies of these crosses are distributed freely to mungbean breeders (Park and Yang, 1978). Exchange of elite varieties and breeding lines is also facilitated by distribution of the International Mungbean Nursery from AVRDC to cooperators in many countries.

The wild and cultivated relatives of mungbean provide another source of breeding materials. Many of the close relatives have genes for disease resistance or other characteristics that would be useful if they could be transferred into the mungbean species.

<u>(*a*) Germplasm Collections</u>. Germplasm collections of mungbean are being assembled and maintained for future use. The largest collection, which contains about 5,000 accessions, has been assembled at AVRDC. Seeds from the accessions are available for distribution to mungbean research workers everywhere. A collection of mungbean germplasm accessions is maintained by the U.S. Department of Agriculture at the Southern Regional Plant Introduction Station, Experiment, Georgia. A catalog of 'Table Legumes' published by the USDA lists 1,925 accessions of *Vigna radiata* and additional accessions of several related species (USDA, 1978). Duplicate samples of USDA accessions are stored in the National Seed Storage Laboratory, Fort Collins, Colorado, a long-term storage facility. National germplasm collections of mungbeans are maintained in India (1,300 accessions), the Philippines (2,200 accessions), Afghanistan, Australia, Bangladesh, and other countries (Ayad and Anishetty, 1980). Mungbean research workers are urged to send samples of novel breeding materials, including wild relatives, to AVRDC and to their national germplasm collections for long-term storage and preservation.

A shortcoming of all large germplasm collections is the duplication or similarity of many varieties or strains within the collection. Duplication greatly increases the resources required to maintain the collection, without contributing to the pool of genetic variability.

(b) Germplasm Characterization. The utility of a germplasm collection would be enhanced if the unique features of each accession were to be described and recorded, so that the research worker could choose those accessions in the collection which have the genetic characteristics desired for his particular research. Some plant characters, are stable over a wide range of environments and may be unmistakably recorded. Other features are so greatly affected by the environment that characterization has little value unless the environment in which the accession is grown is described. For example, the lobed leaf character of mungbean could be identified in almost any environment, but resistance to a particular virus could not be identified unless conditions were favorable for virus inoculation and disease development. Another problem is that many accessions in the germplasm collection are genetic mixtures and give a mixed response. However, this should not hinder attempts to obtain the most complete and accurate information possible on each accession with the resources available.

Various research workers have assembled collections of mungbeans and classified them by grouping together strains with similar characteristics (Piper and Morse, 1914; San Miguel, 1916; Bose, 1932A, Caquicla, 1933; Banks, 1958; Yohe and Poehlman, 1972; Gill et al., 1975; USDA, 1978). Bose (1932A) based his classification on seed color, flower color, pod color, foliage color, growth habit, and time of maturity. Similar characteristics were used by Caquicla (1933) and Banks (1958). The USDA collection (U.S.D.A., 1978) is described according to maturity, plant type, plant height, pod length, and pod color. While these descriptors are useful for identification purposes, they do not describe such characters as photoperiod response, disease resistance, or quality which are important to the breeder. Descriptors used by Gill et al. (1975) were more complete, providing information on maturity; seed weight; seed yield; protein content; and disease scores for yellow mosaic virus, bacterial blight, and *Cercospora* leaf spot.

To promote the collection, conservation, evaluation, and documentation of the germplasm resources in crop plants, the Food and Agricultural Organization of the United Nations sponsors the International Board for Plant Genetic Resources (IBPGR). In March, 1980, a Working Group was convened by IBPGR to develop descriptors for the mungbean germplasm collections. The descriptors include morphological characteristics, environmental adaptability, agronomic characteristics, disease and insect resistance, and quality characteristics (Food and Agricultural Organization, 1980). Use of specific descriptors for characterization of accessions in a mungbean collection should encourage more completeness, accuracy, and uniformity in recording information. Computer processing of information and its recall through information retrieval systems will also be facilitated.

Breeding Procedures

Mungbean is self-pollinated, individual plants within a population tend to be homozygous and true breeding. Breeding procedures for self-pollinated crops in general were described by Poehlman (1979), and for pulse crops by Poehlman and Borthakur (1969). In mungbean, the basic breeding procedures are *(a)* selection and *(b)* hybridization.

(a) Selection. Most native varieties of mungbean will be mixtures of homozygous genotypes which may be similar overall, but will differ in specific performance. The first step in improving a mixed native variety, is to isolate and increase the best component pure lines. After superior lines have been isolated, they may be increased as a variety or similar lines may be bulked to form a mass selection. The mass selection will never perform as well as the best component line in any particular situation, but may perform more consistently than a single line over a variety of environments, due to the buffering effect of the different genotypes within the population. The pure line variety is a more uniform population than a mass selection. In addition to the isolation of lines from mixed varieties, selection is used to isolate superior lines from segregating generations following hybridization.

(b) Hybridization. After superior lines have been isolated and characterized, hybridization is used to combine the desirable characteristics of two or more lines into one strain. Superior lines isolated following hybridization are increased and tested for performance in yield trials. Earlier, hybridization did not receive much attention in mungbean breeding. Either native varieties or selections from native varieties were grown. Now hybridization is used extensively, and almost all new varieties originate by this breeding procedure. The increase in the use of the hybridization breeding procedure is the result of *(a)* favorable characteristics of new lines being identified more fully so that breeders can choose desirable parent combinations with greater precision; and *(b)* crossing procedures being improved and standardized so that a higher percentage of seed set is obtained.

(c) Backcrossing. The backcross is a hybridization procedure in which single genes from an otherwise undesirable variety may be added to a desirable variety. The backcross may be utilized in mungbean breeding following the same procedures successfully followed in self-pollinated cereals or in soybeans (Poehlman, 1979).

(d) Multiple-Crossing. Most crossing in mungbean has been limited to two-parent crosses in which the parents were chosen for specific characteristics. Through multiple-crossing, it is possible to combine the characteristics of several parents, or to obtain a wider spectrum of gene recombinations for characters inherited in a quantitative manner. Pairs of F_1's are crossed until all of the original parents enter into the final cross. Segregating generations of these germplasm pools are then increased and superior plants selected from them.

Breeding Objectives

The characteristics bred into new varieties are determined by the objectives of the breeding program. Breeding in mungbean has received less attention than has been given to breeding of some of the pulse crops. This has limited the progress made and left the objectives less clearly defined. Mungbean is generally regarded as a low yield crop, with yields that fluctuate widely under different environmental conditions. This emphasizes the need for improving not only its yield potential but also its yield stability. In these respects, the breeding objectives in mungbean do not differ in substance from those of other pulse crops.

(*a*) Seed Yield. Breeding for improved grain yield in mungbean involves (*a*) concentration of genes for genetic potential to produce high seed yields, and (*b*) incorporation into varieties of high yield potential genes for tolerance to stress conditions that limit expression of the genetic potential. Evaluation for maximum yield potential requires the comparison of varieties in an optimum environment, where soil fertility, soil moisture, or disease, is not limiting plant growth and development, whereas evaluation for tolerance to stress requires exposure to the stress conditions receiving consideration. Most mungbean varieties have evolved under stress environments and do not have the superior yield potential desired.

How can mungbean varieties be developed with superior yield potential, and how does the breeder identify the superior genotype? The traditional approach has been to compare large numbers of varieties over a series of environments and choose the variety with the superior yield. With this empirical approach it is usually not possible to identify the characteristic of the variety which contributes to the high yield potential, or to identify the characteristics of the environment which permit the superior yield potential to be expressed. A second approach, employing biometrical methods, evaluates the relationship or contributions of the individual yield components to the total yield. Correlation and path coefficient analyses have identified the importance of high pod number for obtaining high yields. The profuse flowering of mungbean suggests that the potential for high pod number is normally present. This potential may be reduced by high flower abortion, or by failure of the plant to mobilize photosynthate and transport it to the potential pod sites. A third approach is directed toward evaluation of strains for physiological processes, such as source-sink relationships, harvest-index, and others. Important here is that the assimilate be partitioned away from vegetative growth and into seed production when flowering begins. The biometrical and physiological approaches are more precise than the empirical approach, and are useful in identifying parent materials for hybridization programs, provided that practical screening techniques are available by which the processes may be measured. A disadvantage of both the biometrical and physiological approach is that they are very time consuming and expensive, and impractical to apply to large numbers of varieties and crosses.

(*b*) Plant Type. To obtain high yielding potential, increased emphasis is being given to plant type (Jain, 1971; 1974; 1975). The idea of "reconstructing plant type" has been borrowed from the concepts associated with the high yielding wheat and rice varieties. In pulses, the "new plant type" refers to shorter, more compact plants with a high harvest index; reduced photoperiod sensitivity; and earlier and more determinate growth habit than in the older and more traditional varieties. Varieties with the new plant type are particularly suited to short summer seasons, high plant populations, and multiple cropping programs where mungbean occupies the land for short periods between major crops (L. Singh, 1975). For maximum grain production, vegetative growth should terminate with flowering and assimilates be channeled into production of pods (Saini and Das, 1979).

High pod set from the first and second flush of blossoms will reduce number of pickings and labor costs. Hand picking and machine harvesting would be further facilitated by concentration of the pods in the top of the plant. Low photoperiod sensitivity permits the variety to be grown in any season of the year. The new plant type is associated with maximum grain yield per day over a short growing season, although not necessarily with maximum grain yield per hectare.

In contrast to the plant type described above, correlation studies suggest that maximum yield per hectare is associated with large plants which have greater height and branching (Prasad, 1959; Gupta and Singh, 1969; Joshi and Kabaria, 1973; Malhotra, Singh and Singh, 1974A; Yohe and Poehlman, 1975). In the Second and Fourth International Mungbean Nursery, highest yields were produced by a late maturing strain from Peru at Melka Werer, Ethiopia, 3032 and 6907 kg/ha, respectively, for two seasons (Poehlman et al., 1974, and 1976). At the Melka Werer location, there was abundant sunshine over a long season throughout which the Peruvian strain continued to set pods due to the indeterminate growth habit of mungbean. In the monsoon season in southeast Asia, the Peruvian strain performed poorly. Saini and Das (1979) found a late variety to exceed the yield of early varieties in seasons with abundant sunshine, but to be lower in yield in a cloudy season. Chowdhury and Haque (1977) suggest that late varieties with a series of reproductive flushes would give more stable yields since flowering would continue after unfavorable weather during the early flowering period. Further studies to identify the characteristics that adapt mungbean varieties for different climatic areas are needed.

(c) Early Maturity and Uniform Maturity. Early maturity has been referred to in relation to plant type and the utilization of mungbean as a short duration crop in multiple cropping systems. To obtain early maturity, genotypes with low photoperiod sensitivity are required for long day environments. At high latitudes, or high altitudes, the length of the growing season is restricted by the frost-free period, requiring use of early ripening varieties. Earliness in mungbean is usually described by days from planting to opening of the first flower, or days to ripening of the first pod. But these criteria are inadequate to describe the flowering pattern since mungbean has an indeterminate growth habit and flowering may continue over a period of several weeks. Pods normally ripen about three weeks after pollination. Mungbean plants may contain flowers, green or immature pods, and ripe pods at the same time, requiring 3 to 5 pickings for harvest. Reduction in the length of the flowering period so as to give more uniform maturity is a major objective in breeding mungbeans. A Philippine variety, PHLV18, matures a large percentage of its pods for the first picking and is being utilized in the AVRDC breeding program to increase uniformity in flowering (Park and Yang, 1978).

(d) Tolerance to Cold and Drought. Mungbean is a warm season crop. Yet, in the semitropics, or at higher altitudes, mungbean may be planted when mean night temperatures are below 20°C. Selection for rapid germination and seedling growth in low temperature environments would improve establishment of stands, promote earlier maturity, and improve grain yields in areas where low temperatures at time of planting impair germination and early seedling growth. Screening techniques for evaluation of germination and seedling growth at low temperatures are needed.

Mungbean is often grown where soil moisture is limited, either intermittently during the life of the plant, or with a declining soil moisture supply. Although mungbean is frequently grown on residual moisture after harvest of rice, there is little information on drought tolerance of mungbean varieties under a declining moisture situation. Screening techniques are needed to observe comparative root development, wilting, stomatal closing and other physiological processes associated with drought tolerance.

(*e*) Disease and Insect Resistance. Mungbean is susceptible to injury from a large number of disease and insect pests. Breeding for resistance is an economical and practical method of reducing pest damage. The problems and progress in breeding for resistance will be discussed in the topics on diseases and insects of mungbean.

(*f*) Quality. Mungbeans are grown mainly for their seeds which are utilitzed as food, and occasionally for livestock feed. The principal breeding efforts directed toward quality thus far has been to select for large and glossy seeds since seeds with these characteristics bring the highest price in the market place. Selection of yellow as well as green-seeded varieties has been practiced in the Philippines. Recently, attention is being given to varietal qualities affecting nutritional properties and cooking characteristics. Varieties have been shown to vary in protein content and content of specific amino acids. Breeding to increase protein content or amino acid balance in cereals has not made the anticipated progress, which suggests that it should be given a low priority in a mungbean breeding program. The opportunity for increasing total protein production by increasing yield deserves far greater attention and, currently, is more likely to succeed than a program to improve protein content or quality.

Varieties

Varieties of mungbean in cultivation have been developed by selection from local strains and by hybridization. Earlier, variety development was almost exclusively by selection from locally collected varieties. Currently, intensive hybridization programs have been developed in several countries.

(*a*) India. Present varieties have evolved from native or land varieties. Collections of native varieties were made in all districts of India in 1925; from these about 40 distinct types were identified (Bose, 1932A). One of the first varieties to be developed, Mung Type 1, was recommended for distribution in 1936, but large scale multiplication and production was not started until 1948 (Mehta and Sahai, 1955). A "Pulse Scheme" was initiated in Uttar Pardesh in 1943 with collection of local strains, and a hybridization program was begun in 1950. In former Madras state, variety CO.1 was selected and released in 1953. Within a few years pure line varieties had been selected and named in all states in which mungbean was important as a crop. Mungbean breeding programs in India have been assisted by organization of an All-India

Coordinated Pulse Improvement Program, and by convening Annual Workshops on Pulse Crops, beginning in 1967. Varieties developed in India by selection have included Type 1, Shining Mung 1, CO.1, CO.3, Jalagon 17, Kopergaon, D45-6, G.65 and others. Varieties developed by hybridization have included Type 2, Type 44, Type 51, Pusa Baisakhi, ML-3, ML-5, Jawahar-45, Kanke Multipurpose, and others. These varieties and others are described in the following references: S. P. Singh (1955), Premsekar and Srinivasan (1961), Bhatnagar et al. (1964), S. G. Singh (1965), Mazumdar, Vasavada, and Joshi (1969), K. B. Singh (1970), H. B. Singh, Joshi, and Thomas (1970), L. Singh, Sharma, and Tomar (1972), Bhullar and Singh (1973), Bhargava (1973), Rathnaswamy et al. (1977), K. B. Singh et al. (1977), De, Turkhede, and Gangasaran (1978), D. P. Singh (1979), and in annual reports of the All-India Coordinated Pulse Project.

(b) Philippines. Local selections and introductions were being tested before 1916 (San Miquel, 1916). A varietal improvement program was undertaken in 1956 by the Bureau of Plant Industry (Ballon, Legaspi, and Catipon, 1978). Local varieties being grown at that time were badly mixed. Pure line selections isolated from local varieties included Glossy Green S-1, Glabrous Green, Dull Green 28-1, Ilag S6A, Iloilo Yellow, and San Pablo Yellow. Varieties produced by hybridization included MG50-10A, MD15-2, Glabrous No. 3, and MY-17. The latter is a yellow seeded variety. MG50-10A-Y is a yellow seeded variety in which the gene for yellow seed color was added to MG50-10A. Some varieties produced by the University of the Philippines, Los Baños, include CES14, CES55, PAGASA 1, and PAGASA 2 (Cortado, 1971; Catedral and Lantican, 1978).

(c) Indonesia. Mungbean varietal development in Indonesia was started in 1935 with a collection of local varieties from which the varieties Silwalik and Artaijo were recommended to farmers (Somaatmadja and Sutarman, 1978). A variety Jala, from Sri Lanka, was distributed in 1965. MG50-10A from the Philippines is also grown.

(d) Thailand. Mostly native varieties are grown which are grouped according to appearance as dull, shiny, golden, and black (Bhumiratana, 1978). An introduced variety of the "Philippine-Type" has been named Uthong 1 (Nalampang, 1978).

(e) U.S.A. Mungbean breeding is conducted at the Oklahoma Agricultural Experiment Station, Stillwater. Three varieties have been developed, Berken, Kiloga, and Oklahoma 12 (Matlock and Oswald, 1963).

(f) Australia. Mungbean is a recent introduction to Australia. Berken, an introduction from Oklahoma, and Celera are grown (Kingston, 1975).

Asian Vegetable Research and Development Center (AVRDC)

The Asian Vegetable Research and Development Center was organized in 1971 at Shanhua, Taiwan, with support from several Asian countries, the U.S.A., and charitable and developmental organizations (AVRDC, 1974). At AVRDC, all areas of research are conducted on mungbean. Thousands of crosses are made in the breeding program. Mungbean breeders benefit from genetic materials being made available from the extensive AVRDC germplasm collection and hybridization program; the International Mungbean Nursery; research in production, physiology, pathology, entomology, and nutrition; training programs; and facilitation of communication among mungbean research workers in national programs (Park and Yang, 1978).

International Mungbean Nursery (IMN)

The International Mungbean Nursery was developed in 1972 to obtain information on (*a*) the range of adaptation of the mungbean species, (*b*) the adaptation of specific mungbean varieties, and (*c*) identification of characteristics of the mungbean plant influencing adaptation (Poehlman et al., 1973, 1974, 1975, and 1976). The first four nurseries were coordinated from the University of Missouri, Columbia, Missouri, U.S.A. Succeeding nurseries have been coordinated through AVRDC.

X DISEASES

Mungbean is host to many diseases. The disease producing agents include fungi, bacteria, viruses, and nematodes. For the disease to develop there must be present the disease agent, a susceptible host, and an environment favorable for the disease agent to multiply and invade the host tissue. Disease may affect production of mungbean in various ways. Seedling diseases reduce stands. Root diseases and nematodes alter or destroy root tissues and interfere with normal water and mineral uptake. By blocking the vascular system they can cause stunting and wilting of above ground parts. Leaf diseases destroy leaves, or portions of leaves, reduce photosynthetic area, and disrupt normal physiological processes. Virus diseases may cause stunting, leaf yellowing, leaf curling, flower deformation, and reduction in pod development. The earlier in the life of the plant that disease develops, the greater the potential for yield reduction.

The major disease control procedures involve (*a*) cultural practices, (*b*) use of chemicals, and (*c*) utilization of resistant varieties. Disease development is reduced by such cultural practices as removal and destruction of infected plant residues and by crop rotation. Vigorous, healthy plants are fostered by balanced fertilization and good water management. Chemical seed protectants will control or reduce injury from certain seed-borne diseases, and foliar fungicides will reduce injury from foliar diseases, but chemicals are seldom used to control diseases in areas where mungbean is grown as a low income crop. Some commonly available chemical seed protectants and foliar fungicides are listed in Table 9. Breeding for resistance to disease pathogens is mostly in the stage of identifying resistant mungbean accessions and making crosses to transfer the resistance genes into adapted cultivars.

Damping-Off, Seedling Blight, Root and Stem Rot

Damping-off, seedling blight, and root and stem rots of mungbean are caused by several groups of fungi: *Rhizoctonia* spp., *Pythium* spp., and *Fusarium* spp. These pathogens, singly or in combination, may cause (*a*) seedlings to rot before emergence, (*b*) the stem of seedlings to rot at or below the soil line after emergence, or (*c*) root rotting or stem cankers on older plants. Destruction of roots by the fungi or damage to the vascular system restricts water intake and movement and causes plants to wilt or die during periods of high temperatures or drought.

(*a*) Rhizoctonia Root Rot, Seedling Blight and Stem Canker. Rhizoctonia disease is caused by *Rhizoctonia solani* Kuehn and *R. bataticola* Taub. *R. solani* is widespread having been reported on mungbeans in India (Grewal, 1978); Iran (Kaiser, 1970; Kaiser, Mossahebi, and Okhovat, 1970); the Philippines (Ilag, 1978); Taiwan (Lai and Wu, 1963; AVRDC, 1974, 1975,

Table 9. Some Commonly Available Chemicals with Fungicidal Properties.[a]

Common Name	Trade Name[b]	Type of Fungicide
Benomyl	Benlate	Systemic foliar fungicide
Canbendazim	Bavistin	Foliar fungicide
Captan	Captan, Orthocide	Seed protectant-eradicant fungicide
Carboxin	Vitavax, Plantvax	Systemic seed protectant fungicide
Chloranil	Chloranil, Spergon	Seed protectant fungicide
Chloroneb	Demosan	Systemic seed protectant fungicide
Daconil	Daconil 2787	Foliar protectant fungicide
Dimethirimol	Milcurb	Systemic eradicant fungicide
Mancozeb	Dithane M-45	Seed protectant fungicide
Maneb	Maneb	Seed protectant fungicide
PCNB	PCNB, Brassicol, Terraclor	Soil fungicide
Sulfur, wettable	Cosan, Sulkol	Foliar fungicide
Thiophanate	Thiophanate, Topsin	Systemic foliar fungicide
Thiram	Arasan, Thylate	Seed protectant fungicide
Zineb	Zineb, Dithane Z-78	Seed protectant and foliar fungicide
Ziram	Ziram	Foliar fungicide

[a]Chemical fungicides should be handled and used only according to directions on the label and in compliance with local regulations.

[b]Trade names are used in this publication solely to provide specific information. Mention of a trade name does not constitute a warranty of the product by the University of Puerto Rico, the U.S. Agency for International Development, or the authors, or an endorsement over other products not mentioned.

1977, 1979); and on blackgram in India (Ranganathan et al., 1973). *R. bataticola* has been reported on mungbean in India (Deshkar, Khare, and Singh, 1974; Grewal, 1978). *R. solani* produces sunken, reddish brown lesions on the seedling hypocotyl at ground level or below, which enlarge and coalesce, girdling the stem and causing the seedling plant to collapse and die. Black dot-like sclerotia are formed in diseased portions of the root and stem. The fungus is primarily soil inhabiting and survives as a saprophyte on soil organic matter, or in decayed root tissue infected with other fungi (AVRDC, 1975). The disease is produced on a large number of crop plants and is most prevalent on plants growing in wet soil. Diseased plants may be concentrated in small patches or scattered over the entire field. *R. solani* infection is more injurious to seedlings than to mature plants. The pathogen is concentrated in the surface layer of the soil where organic matter is present in most abundance (Kaiser, 1970).

R. solani produces maximum disease at a temperature around 20°C and in wet and alkaline soils (Kataria and Grover, 1976). Disease injury may be reduced by crop rotation, timing of plantings to avoid periods of low temperature, and draining wet areas of the field. Chemical seed treatments to control seedling blight by *R. solani* have given variable results (Table 10).

Table 10. Summary of Seed Treatments for Control of Seedling Blight of Mungbean Caused by *Rhizoctonia solani* Kuhn.

Treatment	Disease[a] Index After 7 Days	Survival[b] After 3 Weeks	Survival[c] After 9 Weeks	Seed[d] Yield
				g/plot
Untreated control	100	0	14	122
Benomyl	25	93		
Captan				168
Carboxin (Plantvax)			18	124
Carboxin (Vitavax)	47	62	58	176
Chloroneb	62	48		231
Mancozeb	98	0		148
PCNB	67	97	79	209
Thiabendazole			72	199
Thiram	96			135

[a] After Sharma, Tiwari, and Kulkarni (1975).

[b] After Jhooty and Bains (1972).

[c] After Kaiser, Mossahebi, and Okhovat (1970).

[d] After Kaiser, Okhovat, and Mossahebi (1970).

In the Philippines, seed treatment with captan, thiram, carboxin, and chloroneb are suggested as a control measure (Ilag, Quebral, and Benigno, 1979). The toxicity of fungicides against *R. solani* may be affected by physical factors such as temperature and pH (Malhan, Tyagi, and Grover, 1975). Breeding for resistance has not offered much promise for reducing disease injury due to the difficulty encountered in finding resistant strains. In India, 163 accessions were tested for resistance by germinating seeds in paper towels after they had been dipped in *R. solani* inoculum; seedlings remaining healthy were inoculated by injecting inoculum into the hypocotyl (Deshkar, Khare, and Singh, 1974). None of the accessions were found to be resistant. At AVRDC, 745 accessions were screened in the field for damping-off caused by the combined effects of *R. solani* and *Pythium* spp.; none were resistant in combined spring and fall screening trials (AVRDC, 1979).

(b) *Pythium* spp. *Pythium aphanidermatum* (Edson) Fitz. and *P. ultimum* Trow are common soil inhabiting fungi that cause seed decay, damping-off, and pre- or post-emergence killing of mungbean seedlings. Infected seedlings that emerge often have dead growing points. In older plants, infection may cause decay of the roots and lower stem, dark brown lesions on the stem, and eventual wilting. The pathogens thrive in wet and alkaline soils. *P. aphanidermatum* is favored by warm temperatures and *P. ultimum* by cool temperatures. The disease is most prevalent in wet, rainy seasons (AVRDC, 1975). Both mungbean and blackgram are hosts (Yang, 1978; Jaganathan et al., 1974; Ilag, Quebral, and Benigno, 1979).

(c) *Fusarium* spp. *Fusarium* pathogens are widespread. Symptoms incited are blighting, blackening of the vascular system in root and stem, and wilting. The pathogen often enters the plant as a secondary invader. In contrast to *Pythium* spp., *Fusarium* spp. is favored by dry, acid soils (AVRDC, 1975). The complex of Pythium and Fusarium diseases are reported to be associated with mungbean root disorders in Iran (Kaiser et al., 1968), India (Williams, Grewal, and Amin, 1968), Taiwan (AVRDC, 1974, 1975, 1977, and 1979), and the Philippines (Ilag, 1978). Cultural procedures that are favorable for rapid germination and growth of mungbean, viz. planting when soil moisture and temperature are optimum and using seed protectant chemicals, are suggested control practices.

Foliar Disease

Foliar diseases of mungbean are caused by both fungi and bacteria.

(a) *Cercospora* Leaf Spot. *Cercospora* leaf spot causes severe leaf spotting and defoliation of mungbean in humid tropical areas of Southeast Asia (Legaspi, Catipon, and Hubbell, 1978; Catedral and Lantican, 1978; Duangploy, 1978; Grewal, 1978; Somaatmadja and Sutarman, 1978). The principal pathogen is *Cercospora canescens* Ell. and G. Martin, although *C. cruenta* has been reported to be a pathogen on mungbean in the Philippines (Welles, 1924; Ilag, 1978), and *C. caracallae* (Speg.) Greene and *C. dolichi* in India (Rath and Grewal, 1973). Brown leaf spots with greyish white centers and reddish brown margins develop on the leaves, causing premature defoliation and loss in yield. As the disease advances, lesions are developed on the stems and pods. The disease spreads by spores from soil debris.

Spores of *C. canescens* are primarily air borne, although some may be seed borne. The disease is most prevalent during the rainy season. Disease severity increases during flowering and pod formation. Conidia production on detached leaves was higher in darkness than in normal light, and optimum at 27°C and 96% humidity (Rath and Grewal, 1973). Starch and sugar content of the mungbean plant is depleted by the pathogen, ostensibly utilized for growth and sporulation of the pathogen (Vidhyasekaran and Kandasamy, 1972).

Although chemicals are seldom used by farmers, injury from *Cercospora* leaf spot may be reduced by foliar fungicides such as benomyl, carbendazim, captan, daconil, or zineb (Srivastava, 1970; Kotasthane and Agrawal, 1976; D. V. Singh and Singh, 1976; Rewal and Bedi, 1976; PCARR, 1977; Grewal, 1978). Screening for resistant germplasm has resulted in identification of three moderately resistant varieties, ML-3, ML-5, and ML-15, from the Punjab Agricultural University in India (Mew, Wang, and Mew, 1975), Pagasa from the Philippines (Quebral, 1978), and blackgram strain VM2156 (AVRDC, 1979). Plants are artificially inoculated by spraying with a spore suspension. Artificial inoculation was difficult previously due to poor sporulation of *C. canescens* on an artificial media. However, when grown on a carrot leaf juice-oatmeal agar media, the pathogen sporulates abundantly (Mew, Wang, and Mew, 1975).

(*b*) Powdery Mildew. Powdery mildew is a common foliar disease of mungbean. It has been reported from Colombia, Ecuador, Ethiopia, Korea, Philippines, Thailand, and U.S.A. (Poehlman et al., 1976), Australia (Bott and Kingston, 1976), Taiwan (AVRDC, 1975), and India (Grewal, 1978). The disease is favored by dry weather, temperatures of 22 to 26°C, and relative humidities of 80 to 88% (Haq, 1978). In Asia, the disease is common in the cool, dry months, and seldom a problem in the warm, rainy season.

The pathogen, *Erysiphe polygoni* D.C., is highly specialized, and infects both mungbean and blackgram. The disease first appears as ash grey spots on the upper surface of the leaves; as the fungus spreads, a mycelium covers the leaf surface, giving the plant a powdery white appearance. In advanced stages, stems and pods become infected and older leaves defoliated. Infection during the seedling stage may result in death. When infected prior to flowering, so that leaves were covered with mycelium at time of flowering, yields were reduced by 21% (Soria and Quebral, 1973). Infection after the pods are set may have only slight effect on yield.

Foliar fungicides such as bavistin and benomyl are effective against *E. polygoni* (Quebral and Lantican, 1969; Kotasthane and Agrawal, 1976; PCARR, 1977; Quebral, 1978). The disease is also effectively controlled by spraying with wettable sulfur (Grewal, 1978) or dimethirimol (AVRDC, personal communication, 1980). As with *Cercospora* leaf spot, farmers seldom spray to control mildew. No high level resistance has been found in mungbean, but a moderate level of resistance has been identified in

ML-3, ML-5, and other varieties from India (AVRDC, 1978) and Pagasa 1 from the Philippines (Catedral and Lantican, 1978).

(c) Scab. Scab, caused by *Elsinoe iwatae* Kajiwara and Mukelar, is a serious disease of mungbean in Indonesia and is also present in the Philippines. The disease affects the leaves, stems, and pods. Lesions on the leaves are small and circular at first, but gradually enlarge, sometimes becoming angular. Older lesions become gray and drop out, giving the leaf a "shot-hole" appearance. With severe infection, the leaves are curled and the plants stunted. Injury from the disease may be reduced by application of foliar fungicides, such as thiophanate, bavistin, or benomyl (Mukelar, Sudjadi, and Kajiwara, 1976; Kajiwara and Mukelar, 1976; Mukelar, 1978).

(d) Anthracnose. Anthracnose, caused by *Colletotrichum lindemuthianum* Sacc. and Magn., has been reported on mungbean in India (Srivastava, 1970) and the Philippines (Ilag, 1978). The disease produces brown, sunken lesions on the cotyledons and young stems, which may increase in size and kill the plant. Pods and seeds may become infected; infected seeds usually fail to germinate. The disease is favored by rainy weather. Disease incidence is reduced by spraying with a fungicide. Resistant selections have been identified in the Philippines (Catedral and Lantican, 1978).

(e) Rust. Rust has been considered to be a minor disease on mungbean, but it is increasing in importance in the Philippines (Ilag, 1978). In Indonesia, rust is usually present on mungbean in the rainy season (Somaatmadja and Sutarman, 1978). Bean rust, which infects mungbean, destroyed a breeding plot of blackgram at Coimbatore, India (Raychaudhuri, 1968; Williams et al., 1968).

The nomenclature of the rust species infecting mungbean needs clarification. Rust fungi collected from mungbean in India were identified as *Uromyces phaseoli* var. *typica* by Raychaudhuri (1968), and *U. appendiculatus* (Pers.) Lk. by Williams et al. (1968). Ilag (1978) identified the rust pathogen in the Philippines as *U. vignae* Barcl. Yang (1977) reports mungbean to be a host to the soybean rust fungus, *Phakopsora pachyrhizi* Syd.

Incidence of rust disease may be reduced by spraying with foliar fungicides such as sulfur, benomyl, thiram (Kannaiyan and Rao, 1974), mancozeb or carboxin (Ilag, Quebral, and Benigno, 1979).

(f) Angular Leaf Spot. Angular leaf spot on mungbean and blackgram has been reported from India (Pavgi and Thirumalachar, 1953; Haware, 1972). The pathogen inciting angular leaf spot is *Protomycopsis patelii* Pavgi and Thirumalachar. Symptoms are pale green, angular spots on the leaves, which gradually become darker in color, finally turning purple-black to opaque. Chlamydospore germination was inhibited by mancozeb, ziram, zineb and other foliar fungicides (Haware and Pavgi, 1969). Mungbean varieties Hy2, Krishna 11, and Khargaon 1, and blackgram varieties T-21 and Ujjain 4 are highly resistant (Haware and Pavgi, 1976). Mungbean varieties are generally more resistant than blackgram varieties.

(*g*) Bacterial Leaf Spot. Bacterial leaf spot, incited by *Xanthomonas phaseoli* (Smith) Dowson is a disease of mungbean, blackgram, and other legumes (Patel and Jindal, 1972; Grewal, 1978). The disease produces small, dry, necrotic pustules. The pustules gradually enlarge and coalesce to form large necrotic blotches which disintegrate to give the leaf a ragged appearance. Streaks or cankers develop on the stem in more severe infections. The disease is favored by warm, wet weather. Cross inoculations on soybeans, cowpeas, blackgram and other legumes suggested that the mungbean bacterial leaf spot pathogen is a distinct race or strain of *X. phaseoli* (Patel and Jindal, 1972). Six pathogenic races have since been identified, with resistance to each being inherited by different single dominant genes (Thakur, Patel, and Verma, 1977A). Resistance to bacterial leaf spot, *Cercospora* leaf spot, and yellow mosaic virus are inherited independently (Thakur, Patel, and Verma, 1977B). Patel, Jindal and Singh (1972) screened 2160 lines for resistance by spraying at the 3- to 4-trifoliate leaf stage with a dilute suspension of *X. phaseoli* and identified 29 resistant and 5 tolerant strains of mungbean. Seed treatment with a seed protectant fungicide will control seed borne bacteria.

(*h*) Halo Blight. Halo blight is a bacterial disease of mungbean incited by *Pseudomonas phaseolicola* (Burk.) Dowson (Schmitthenner, Hoitink, and Kroetz, 1971; Patel and Jindal, 1972). The disease produces watersoaked lesions on the underside of the leaf which are surrounded by a chlorotic halo visible on both sides of the leaf. The pathogen is soil borne and seed borne. Control remedies include spraying, planting disease-free seed, and resistant varieties. In Ohio, U.S.A., a variety from Peru (C.I.378023) was resistant (Schmitthenner et al., 1971). In India the variety Jalgaon 781 was resistant (Patel and Jindal, 1972).

Pod Rots

Diseases which produce rotting of the pods have been identified in India and the Philippines. In India, Phytophthora pod blight, incited by *Phytophthora* spp., produces pale, watersoaked lesions and a white mycelium on the pods, which eventually rot (Srivastava, 1970). In the Philippines, a Diplodia pod rot, caused by *Diplodia natalensis* Pole Evans, starts as a soft rot in young pods (Ilag and Marfil, 1977; Ilag, 1978). Within 3 to 5 days the pod turns brown or black and eventually becomes dry and hard. Seeds in infected pods are shriveled and dark in color. Unfilled and immature pods are most susceptible; resistance increases as the pods become mature. Infected seeds fail to germinate. Varietal differences in resistance was observed.

Virus Diseases

Mungbean is host to many virus diseases. Most of the viruses also infect blackgram. Some cause serious injury and economic loss, others have only minor economic importance. With a few exceptions, the viruses of mungbean and blackgram need further study and clarification of their distinguishing features. Viruses are difficult to identify; host range and symptoms, virus particle size and shape, transmission mode, serology, and other physical and chemical properties of the viruses are required for accurate identification. Symptoms may be confusing due to multiple infections of viruses in the same plant. Laboratory inoculations have shown mungbeans to be a host to viruses which have not been identified from natural field infections. Many of the reports on virus diseases in mungbean do not give a full and accurate description of the symptoms or causal agents of the virus.

(a) Alfalfa Mosaic Virus (AMV). Alfalfa mosaic virus (AMV) infects mungbean in Iran (Kaiser, Mossahebi, and Okhovat, 1971; Kaiser et al., 1972; Kaiser, 1979). Symptoms of AMV on mungbean are stunting, leaf yellowing, and leaflet deformation. The virus is transmitted by several aphid species and is non-persistent. Symptoms resemble those of cucumber mosaic virus (CMV) and the disease is distinguished with certainty from CMV only through serology tests. The disease in mungbean is not considered to have much economic importance in Iran since generally less than 1% of the plants within a field are infected. No sources of resistance in mungbean have been identified.

(b) Bean Common Mosaic Virus (BCMV). Bean common mosaic virus (BCMV) is a seed-borne, aphid-transmitted virus, infecting beans and mungbeans. BCMV is the most common mungbean disease in Iran (Kaiser, Mossahebi, and Okhovat, 1971; Kaiser and Mossahebi, 1974). Symptoms include leaf mosaic, puckering, blistering, rolling, and deformation. Yield is reduced if virus infection occurs before pod set. The virus is transmitted by aphids, sap inoculation, and infected seeds. Several aphid species, *Aphis craccivora*, *Acyrthosiphon pisum*, and *A. sesbaniae*, transmit the virus in a nonpersistent, stylet-born manner. Seed transmission ranged from 8% to 32%. Different strains of the virus were isolated from bean and mungbean in Iran, the two strains having different host ranges. In Iran, 1112 mungbean lines were screened for resistance. When the virus-free lines were screened again the following season, only 2 lines remained free of virus. No control measures have been reported for BCMV in mungbeans, but virus-free seed is essential to prevent its spread. BCMV also infects blackgram (Nelson, 1932).

(c) Cucumber Mosaic Virus (CMV). Cucumber mosaic virus has been reported as naturally infecting mungbean in Iran (Kaiser, Mossahebi, and Okhovat, 1971; Kaiser et al., 1972) and in Missouri, U.S.A. (Purivirojkul and Poehlman, 1977; Purivirojkul et al., 1978). The disease in mungbean consists of dark and light green mosaic pattern, puckering and blistering of the trifoliate leaves, stunting, and flower abortion. Severity of the disease and loss in yield varies with the strain of mungbeans. The causal fungus has been identified through host range studies, electron microscopy, and serology (Purivirojkul et al., 1978). The virus is transmitted by sap inoculation and is seed-borne with low efficiency. It is acquired and transmitted by the cowpea aphid, *Aphis craccivora*, during brief probes. The virus is nonpersistent. A strain of CMV naturally infecting beans in New York, U.S.A., also infected mungbean, but differs from the strain in Missouri (Provvidenti, 1976). The strain identified in Missouri, named CMV-M, produced local lesions when primary leaves of resistant varieties were sap inoculated, but was transmitted systemically to trifoliate leaves in susceptible varieties. Resistance was inherited as a single dominant gene (Sittiyos, Poehlman, and Sehgal, 1979). Seed transmission of CMV was reported in seed originating in Iran (Phatak, 1974), Missouri (Sittiyos et al., 1979), and Taiwan (Iwaki, 1978).

Damage from CMV was assessed in Missouri by growing mungbeans in screened cages to exclude the aphid vector, and in adjacent field plots exposed to the vector. In the unprotected plots, the strain with the greatest injury produced only 5% of the dry weight of the resistant check. This compared to 114% of the dry weight of the resistant check for the same strain inside the cage (Purivirojkul and Poehlman, 1977).

(d) Greengram Mosaic (GGM). A virus causing a mosaic disease was isolated from mungbean in southern India. The virus is aphid and sap transmissible. It was not serologically related to tobacco mosaic virus, cowpea mosaic virus, soybean mosaic virus, or potato virus X. The virus disease caused considerable economic loss to mungbean in Tamil Nadu state of India (Ramakrishnan et al., 1973).

(e) Leaf Crinkle Virus (LCV). Leaf crinkle virus was first observed on blackgram in India by Williams et al. (1968), and was later reported and described by Kolte and Nene (1972), Nene and Kolte (1972), and Nene (1973A). Although commonly found on blackgram in India, mungbean is a host also. Symptoms of the disease are crinkling, curling, puckering, and rugosity of leaves; stunting of plants; and malformation of flowers. Spread of the disease in the field is relatively slow, but injury in blackgram may be severe if infection occurs in young plants. Seed yield reduction of 62% was reported by Nene and Kolte (1972). The extent of natural infection in mungbean in India is unknown.

The virus is transmitted in blackgram by sap inoculation, grafting, insects, and seed. *Aphis craccivora* and *A. gossypii* are vectors (Dhingra, 1975). Seed transmission of 18% to 42% in blackgram has been reported, with seed transmission being reduced as age of the plant at time of inoculation increases (Narayanasamy and Jaganathan, 1975). Nene and Kolte (1972) screened 13 blackgram varieties and 12 mungbean varieties for resistance. All blackgram varieties were susceptible, but 5 mungbean varieties were resistant. Some varieties of blackgram were reported to be highly resistant to LCV by Narayanasamy and Jaganathan (1973).

(f) Leaf Curl. Leaf curl is a virus disease of mungbean and blackgram (Nene, 1973A; Nene and Singh, 1972). Symptoms are chlorosis around lateral leaf veins, rolling and downward curling of the leaf margin, reddish brown discoloration on the leaf undersurface, and stunting of the plant. Plants infected while young either die or become permanently stunted. Plants older at time of infection may produce a few pods with small seeds. The disease is transmitted by sap inoculation and grafting. Local lesions appear on sap inoculated leaves, the lesions later becoming necrotic. Cowpea variety C-20 is a local lesion host (Ghanekar and Beniwal, 1975). Although neither seed nor insect transmission had been confirmed, fields of mungbean in Uttar Pradesh, India, had up to 42% infected plants. Resistant varieties of mungbean and blackgram have been identified (Nene and Singh, 1972).

(g) Mosaic of Blackgram, Mosaic Mottle. A mosaic disease of blackgram was described by Shahare and Raychaudhuri (1963). Symptoms are a mosaic of light and green patches on the leaf, upward rolling of the leaf margin, and blistering of the leaf blade. Nene and Srivastava (1972) named the disease "mosaic mottle" and listed mungbean as a host in addition to blackgram. The virus could be mechanically transmitted, and seed transmission of 3% to 4% was obtained. The disease is widespread in north India (Nene, 1973A).

(*h*) Mungbean Mottle. A virus was isolated from mungbean growing in the Philippines that induced chlorotic spots along the veins in inoculated primary leaves and chlorotic areas in the emerging trifoliate leaves (Talens, 1978). The disease was named mungbean mottle. The virus is mechanically transmitted and possesses serological properties similar to blackgram mottle virus.

(*i*) Tobacco Mosaic (TMV). A virus isolated from mungbean in Tamil Nadu state, India, was identified as a strain of tobacco mosaic virus (TMV) (Ramakrishnan et al., 1969). Infected plants showed slight stunting, and mosaic mottling in infected leaves. The virus is transmitted by sap inoculation.

(*j*) Yellow Mosaic Virus (YMV). Yellow mosaic, also called mungbean yellow mosaic, is the most devastating viral disease of mungbean and blackgram in the Indian subcontinent and adjacent areas (Nariani, 1960; Williams et al., 1968; Nene, Rathi et al., 1972; Nene, 1973A; Ahmad and Harwood, 1973; Varma, Kadian, and Singh, 1973; Iwaki and Auzay, 1978; Benigno and Dolores, 1978; Legaspi, Catipon, and Hubbell, 1978; Grewal, 1978). Symptoms of YMV first appear as small yellow spots on young leaves and develop into yellow and green patches, or completely yellow leaves in advanced stages. Diseased plants are stunted, maturity is delayed, and few or no pods develop. Plants infected at an early age may be killed before flowering. The disease is transmitted by the whitefly, *Bemisia tabaci* Gen., and by grafting. It is not transmitted mechanically or through seeds.

Transmission studies have been made by Nene, Rathi et al. (1972), Rathi and Nene (1976), and Murugesan and Chelliah (1977). The whitefly acquires the virus during a 15- to 60-minute feeding period. After a 3- to 8-hour incubation period, the virus is transmitted during a 10- to 60-minute inoculation period. A single whitefly was sufficient to inoculate 8 of 32 plants, and 10 flies inoculated all of 20 plants. The virus is classified as a circulative type. It persists in the male adult whitefly for 3 days and in the female adult for 10 days (Rathi and Nene, 1974). Varieties differ in type of reaction. Susceptible varieties exhibit a yellow mottle reaction and resistant varieties exhibit a necrotic mottle (Nair, Nene, and Naresh, 1974). Varieties with the yellow mottle reaction are better sources of virus for acquisition feeding than varieties with the necrotic mottle reaction (Rathi and Nene, 1976). The leafhopper, *Empoasca kerri* Pruthi, has a feeding preference for YMV diseased leaf tissue over healthy tissue (Regupathy et al., 1975).

Yellow mosaic occurs mostly in summer (March to May) in Southern and Eastern India (Nene, Rathi et al., 1972; Misra, Tripathy, and Sahu, 1978), months in which the whitefly have the highest populations (Murugesan, Chelliah, and Murugesan, 1977). Spraying to control the whitefly vector at fortnightly intervals reduced the disease incidence, but the effect of control on yield was not reported (Mathur, Banerjee, and Bajpai, 1965).

Moderate resistance to YMV has been reported for a few mungbean varieties, like T-1, BR-1, BR-2, Hybrid 45, PS16, and T-9, and D 6-7 blackgram varieties (Nene, Rathi et al., 1972; Nene, Srivastava, and Naresh, 1972; Sivaprakasam et al., 1974; and others). However, the most effective resistance has been identified in strains developed at the Punjab Agricultural University such as ML-1, ML-5, ML-7, LM-214, and others (Virmani, Singh, and Singh, 1976; Poehlman et al., 1976; Pandya, Singh, and Sharma, 1977; Sandhu, 1978). Resistance has also been identified in a wild relative, *Vigna radiata* var. *sublobata* Roxb. (Verdc.) (formerly *Phaseolus sublobatus*) collected from northern India (B. V. Singh and Ahuja, 1977). Inheritance of resistance to YMV is reported to be monogenic and recessive with variety 24-2 as the resistant parent (D. Singh and Patel, 1977), and digenic and recessive with varieties Tarai Local, L-80, L294-1, and LM 214 as resistant or tolerant parents (Shukla, Pandya, and Singh, 1978).

(k) Other Virus Diseases. Mungbean has been reported host to other virus diseases. In some instances, the infections were from artificial inoculations only, the virus not having been isolated from naturally infected field-grown plants.

(l) Little Leaf. A disease in which trifoliate leaves are reduced in size has been reported from the Philippines (Benigno and Dolores, 1978). The disease causing agent, suspected as being a mycoplasm, is aphid and seed transmitted, but not by mechanical transmission.

Nematodes

Mungbean is a host to several plant parasitic nematodes. Injury to mungbean by natural infestation with nematodes has been reported from the Philippines (Castillo, 1971 and 1975; Castillo, Alejar, and Litsinger, 1976; Castillo and Litsinger, 1978); India (Prasad et al., 1971); Iran (Amirshahi, 1978); and Taiwan (Yang, 1978). Ten genera of nematodes were associated with mungbean in the Philippines, but four species of the root knot nematode, *Meloidogyne incognita*, *M. incognita acrita*, *M. arenaria*, and *M. javanica*, and the reniform nematode, *Rotylenchulus reniformis* were the most important (Castillo, 1975). The mungbean is a host to the soybean cyst nematode, *Heterodera glycines* in the U.S.A. (Epps and Chambers, 1959), and to *M. javanica* and *H. vigni* in India (Prasad et al., 1971; Gupta and Edward, 1974). Injury may be compounded by a mixture of several species of nematodes.

Symptoms associated with nematode injury are leaf chlorosis, wilting, stunting, and formation of galls on the roots (Bajet and Castillo, 1974; Catibog and Castillo, 1975; Castillo, Alejar, and Litsinger, 1977). The root system is reduced in size, the root vascular system is blocked or disrupted, and water and nutrient uptake restricted. Fungi and bacteria may enter as secondary invaders. Injured plants tend to flower early, and pod production and grain yields are reduced. Newly germinated seedlings may fail to emerge following massive nematode invasion.

Mungbean is more susceptible to nematode injury than soybeans or peanuts (Bajet and Castillo, 1974). Yields of mungbean in the Philippines inoculated with *R. reniformis* and *M. acrita* were reduced 62% as compared to the uninoculated check (Castillo, Alejar, and Litsinger, 1977). In the nematode inoculated plots, leaf chlorosis was most apparent when it was hot and dry. With irrigation, the leaves became green, but chlorosis reappeared each time the soil became deficient in moisture. With time, the plants deteriorated and became stunted.

Changes in populations of *R. reniformis* in mungbean were studied over two wet cropping periods and one dry cropping period (Castillo, Arceo, and Litsinger, 1977/78). Nematode population counts were made from 300 g soil and 1 g mungbean roots. Averaged over the two wet seasons, the nematode population increased from 141 to 726 and during the dry season increased from 17 to 509. Yields were decreased 21% during the wet season and 73% during the dry season, in comparison with yield of nematocide treated check plots. These data indicate that nematode injury to the roots is intensified when the soil moisture is deficient.

Nematodes may be controlled through (*a*) crop rotation, (*b*) nematocide chemicals, and (*c*) resistant varieties. Cropping studies in the Philippines show that the nematode population in the soil increased more rapidly with three successive croppings of mungbeans than with three successive croppings of sweet potato or soybean. A higher nematode population was reached in the mungbean with each successive crop. The nematode population may be kept in check by a sequence of two or more successive nonhost crops such as corn or sorghum, or by periods of fallow (Castillo, Bajet, and Harwood, 1975/76). If the corn or sorghum is followed by mungbean, the nematode population immediately increases again. Nematode populations are sharply reduced by cropping with flooded rice.

Nematocide chemicals, Carbofuran 3C and Nemacur, reduced but did not eliminate the nematode population in the Philippines (Castillo and Litsinger, 1978). With one subsequent cropping to mungbean, the nematode population increases. Varieties of mungbean differ in resistance to nematode injury. Resistant varieties have been identified at AVRDC (AVRDC, 1979).

XI INSECT PESTS

Mungbean and blackgram are subject to attack by many insects, but the species and their relative importance have not been well recorded. Ooi (1973) describes 13 insect predators of mungbean in Malaysia. Insects pests identified on grain legumes in Pakistan are reported by Ahmad (1975). Litsinger, Price et al. (1978) listed 26 insect species attacking mungbean in three provinces of the Philippines during 1975-76. The major grain legume pests in several countries of Asia, Australia, Africa, and the Americas are discussed by contributors to "Pests of Grain Legumes: Ecology and Control: (S. R. Singh, Van Emden, and Taylor, editors, 1978).

In a mungbean field, several insect species may be feeding on the mungbean plant simultaneously. Under these conditions evaluation of the economic importance of single species is usually difficult. This emphasizes the need for developing a comprehensive insect control program according to the insect predators present on mungbean in different production areas. Surveys show insect pests to be more common on soybeans in the tropical than in temperate climates. Because mungbean is largely grown in tropical climates, insect control may be expected to play an important role in practices developed for successful production of the crop.

Major Insect Pests of Mungbean

The insect pests of mungbean may differ from area to area, or from season to season within an area. Major insects identified on mungbean in a survey in three provinces in the Philippines are listed in Table 11. The list includes species which attack all plant parts--roots, stems, leaves, flowers, pods, and seeds.

(a) Seedling Infesting. The principal seedling infesting insect is the beanfly (Hua, 1967, Sepswasdi and Moksongsee, 1971; Litsinger, Price et al., 1978; Saxena, 1978; Rose, Chiang, and Harnoto, 1978).

Beanfly (*Ophiomyia phaseoli* Tryon). The adult beanfly deposits eggs in punctures in the leaf tissue. The larvae tunnel through the leaf tissue until they reach a vein, which they follow down through the petiole and stem, pupating near the soil level. Seedlings usually wilt and die. Infestation and seedling loss can approach 100%. Older plants not killed are stunted. The tunnels caused by larval feeding provide avenues for secondary invasion by disease pathogens. In Taiwan, peak populations of beanfly occur in late summer and fall, with up to 90% of the plants being infested (AVRDC, 1977). Some injury may be avoided by adjusting mungbean planting dates to miss periods of high beanfly population, or by high seeding rates to increase the number of plants that may survive infestation. Systemic soil insecticides applied at the time of planting are fairly effective in protecting seedling plants (Hua, 1967; Sepswasdi and Moksongsee, 1971; Su, Kung, and Rose, 1976).

Table 11. Some Insects Identified on Mungbean in the Philippines.[a]

Common Name	Scientific Name	Type of Injury
Beanfly	*Ophiomyia phaseoli* Tryon	Stem borer
Flea bettle	*Longitarsus manilensis* Weise	Plant stunting
Leafhopper	*Empoasca biguttula* Shiraki	Plant stunting
Aphid, cowpea aphid	*Aphis* sp., *Aphis craccivora* Koch	Plant stunting
Leaf folder and leaf roller	*Lamprosema indicata* *Homona* sp., *Sylepta* sp.	Defoliation
Semilooper	*Chrysodeixis chalcites* Esper	Defoliation
Katydid	*Phaneruptera furcifera* Stal	Defoliation
Leaf miner	*Stomopteryx subsecivella* Zeller	Defoliation
Bean thrips	*Taeniothrips longistylus* Karny	Injures buds
Bean lycaenid	*Catochrysops cnejus* Fabricius	Defoliation, feeds on flowers
Corn earworm	*Heliothis zea* Boddie	Defoliation, feeds on flowers, seed loss
Bean pod borer	*Maruca testulalis* Geyer	Pod borer
Lima bean pod borer	*Etiella zinckenella* Tretsche	Pod borer
Green stink bug	*Nezara viridula* L.	Injures pods and seeds
Bruchid, seed weevil	*Callosobruchus* sp.	Destroy stored seeds

[a]Adapted from Litsinger, Price, Herrera, Bandong, Lumaban, Quirino, and Castillo (1978).

Moderate resistance has been identified in varieties Tagalog and Dull 60-5 in the Philippines (Balboa, 1972) and in varieties in Taiwan (AVRDC, 1977, 1978A, 1979; Chiang and Talekar, 1980). The rice bean (*Vigna umbellata*) is more resistant than mungbean, as measured by number of leaf punctures, number of beanflies per plant, and percent plants damaged (AVRDC, 1977, Chiang, Su, and Rose, 1978).

(b) Leaf Piercing and Leaf Sucking Species.

Leafhopper (*Empoasa* sp.). Eggs are oviposited into veins and petioles of the mungbean plant. The nymphs and adults generally feed on the underside of the leaf. With heavy infestation the leaves curl at the edges and turn brown giving rise to the term "hopperburn." Young plants infested with leaf-hoppers may be stunted. Systemic insecticides are effective in reducing leafhopper damage.

Aphids (*Aphis craccivora*, *Aphis* sp.). Aphids feed by thrusting sharp stylets in among the plant tissue cells and sucking out the sap. Aphid colonies multiply rapidly. The massive feeding which follows injures the plant from loss of sap, or by poisoning from toxin injected with the saliva. Leaves turn yellow or brown and plants may become stunted. Additionally, aphids serve as vectors for several virus diseases. Aphid populations may be reduced by contact and systemic insecticides. The insecticides also destroy natural predators which build up and assist in keeping the aphid population under control. In screening tests conducted at AVRDC in Taiwan, a few mungbean varieties with moderate resistance to the cowpea aphid were identified (AVRDC, 1978A; Chiang, Su, and Rose, 1978).

Whitefly (*Bemisia tabaci* Gennadius). The whitefly is a vector of the yellow mosaic virus disease on mungbean and blackgram. The economic loss from the virus disease is much greater than loss from injury caused by insect feeding. The whitefly can acquire or transmit YMV within a 15 minute feeding period. To be effective, insecticides must kill the whitefly within 15 minutes of its alighting on the mungbean plant (Nene, Rathi et al., 1972). None of the contact or systemic insecticides tested in India gave 100% kill of the whiteflies quickly enough to prevent acquisition or inoculation with YMV. The most effective treatment was a 2% nonphytotoxic mineral oil spray. The whitefly becomes covered with the oil within 3 to 9 seconds after alighting on the plant and is unable to feed. Fifty percent mortality of whitefly was reached in 15 minutes and 100% in 30 minutes following the mineral oil spray. This compares with 30 minutes and 1 hour, respectively, to obtain 50% and 100% control with malathion. The emulsifiable oil sprays are washed off by water and, if used, would need to be replaced after each rain. A fungal parasite of *Bemisia tabaci* has been identified in northern India (Nene, 1973B). How effective it is in controlling the whitefly is not known.

(c) Defoliating Species. Many species of insects defoliate mungbean, feeding primarily on leaves, although they may feed on other plant parts. These insect predators include the leaf-rollers, leaf-folders, loopers, cutworms, armyworms, corn ear worms, and other larvae of the order Lepidoptera; herbivorous or plant eating leaf beetles and flea beetles of the order Coleoptera; and grasshoppers, katydids, and locusts of the order Orthoptera. Over one-half of the 26 insect species recorded by Litsinger, Pric. et al. (1978) in the Philippines were defoliating insects (see Table 11). The species vary in different areas and seasons. The extent of damage from defoliating insects is difficult to estimate, but will generally be less than the proportionate loss in foliage since new branches and leaves may develop, partially compensating for the destroyed parts. The reduction in yield from defoliation will be affected by the magnitude of the foliage loss, the stage of plant development at the time of defoliation, and the ability of the plant to replace the destroyed parts. In soybeans, yields were not reduced by a 17% defoliation loss during any growth stage, or a 33% defoliation loss at midbloom (Hinson and Hartwig, 1977). Beetles feeding on mungbean may serve as vectors for certain virus diseases as well. Numerous systemic and contact insecticides are effective in controlling defoliating insects. Varietal resistance to defoliating insects has not been identified.

(*d*) Bud, Flower, and Pod Feeding. In addition to leaf feeding, some insects such as the corn earworm (*Heliothis armigera* Hubner) and bean lycaenid (*Catochrysops cnejus* Fabricius) feed on buds, flowers, pollen, or immature pods of mungbean. Injury or destruction of these plant parts by the corn earworm or the bean lycaenid, or other insects such as bean thrips (*Taeniothrips longistylus* Karny), will reduce pod set and yield. Another destructive insect on mungbean is the stink bug (*Nezara viridula* L.) which damages pods and seeds with its piercing mouthparts. Pods may fail to develop, or seeds may be shriveled from the punctures. Contact insecticides are usually effective for control of these insects.

(*e*) Pods Borers.

Bean Pod Borers (*Maruca testulalis* Geyer; *Etiella zinckenella* Tretsch.). Eggs are laid on petals and sepals. The larvae feed on the flowers and bore into the pods. Young larvae of *M. testulalis* may cause flower bud shedding, or destroy flower reproductive parts. The insect is wide spread geographically and is said to be one of the serious preharvest pests of grain legumes in Nigeria (Taylor, 1978). Chemical control of pod borers is difficult due to the larvae feeding inside the pod where they are protected from insecticides. Insecticide sprays must be timed to kill the larvae between the time they hatch and the time they enter the pod (Taylor, 1978). Mungbean flowers open over a period of several weeks, so three or more spray applications are needed to give control. In the Philippines, seed loss from the pod borer is reported to be relatively small compared to that from leaf-feeding insects (Litsinger, Quirino et al., 1978). Some mungbean accessions with moderate resistance have been found at AVRDC (AVRDC, 1978B, 1979).

(*f*) Root Insects. The toy beetle white grub (*Leucopholis irrotata* Chevrolat) attacks mungbean in the Philippines (PCARR, 1977). The larvae feed on the root system of the mungbean plants. The extent of injury is not known.

(g) Storage Insects.

Callosobruchus Seed Weevils (*Callosobruchus* spp.). The cowpea seed weevil (*C. maculatus* F.) and adzuki bean weevil (*C. chinensis* L.) are destructive storage pests of grain legumes in the tropics. The Callosobruchus weevils or bruchids are present in all tropical and subtropical climates (Southgate, 1978). Field infestation begins with eggs laid on mature green pods. The larvae bore through the pod and enter the developing grain. Field infested seed placed in storage serves as a source of infestation for stored seed. In storage, eggs are deposited on the seed coat of the dry seed. The larvae bore into the seed and hollow out the interior as they feed. After pupation, the adults emerge, leaving holes where they exit, and deposit eggs on sound seeds starting a new cycle. The cycle from egg to adult requires three to four weeks. If uninterrupted, infestation may continue until all seeds are destroyed. Control involves sanitation of storage premises, storage of clean uninfested seed, and eradication by fumigation. Coating stored mungbean seed with a thin coat of peanut or mustard oil inhibits oviposition and protects seeds from infestation for 4 to 5 months (Park, 1978A; Varma and Pandey, 1978). Mixing wood ashes or sand with stored seed inhibits movement of the beetles and reduces infestation damage.

Mungbean accessions were screened for resistance to *C. chinensis* at AVRDC (AVRDC, 1979). Two accessions, VM2011 and VM3529, were free from field infestation with bruchids, presumable because the pubescent pods entangled the adults so that they were unable to lay eggs. If adult bruchids were confined with seeds of the two accessions, completion of the life cycle was delayed for several weeks, suggesting antibiosis in the seeds in addition to the mechanical resistance in the pods (AVRDC, 1979).

Insect Control

In the tropics, mungbean is rotated in small fields in various cropping patterns. At any time, it will constitute only a small percentage of the total cultivated area. This cropping pattern mitigates against large scale buildup of an insect pest that would feed exclusively on the mungbean plant. On the other hand, mungbean serves as host to a large number of insect species, that feed on other crop plants as well. Because mungbean in tropical countries may be grown in almost any season, a succession of plantings may keep certain predator insects at higher populations than would be the case if mungbean production was limited to a single season. Insect control practices in mungbean depend on cultural practices, natural control agents, chemical insecticides, and resistant varieties.

(a) Cultural Practices. Various cultural practices serve to keep an insect population in check, although complete control will not be realized by cultural practices alone. Cultural practices that may be useful are *(a)* altering planting dates to avoid peak insect populations, *(b)* use of crop rotations to avoid build-up of a particular insect species, *(c)* increasing plant density to compensate for plants that may be destroyed, *(d)* control of weeds that serve as alternate hosts, *(e)* employment of mixed

cropping to alter the succession and intensity of insect pest build-up, and (6) clean cultivation to reduce weed host plants and destroy places of hibernation. Hand picking of insects and egg masses may be practiced in small fields. Trap crops may be planted early to obtain a concentration of an insect, with the insect being destroyed then by an insecticide. Cultural practices should be developed that will augment reproduction of beneficial insect predators. Because mungbeans are grown in many countries which differ in climatic conditions and sophistication of cultural practices, local research is needed to develop practices that will be most effective for insect pest control in the local environment.

(b) Natural Control Agents. Natural control agents, such as predator species, parasites, and pathogens, can be important in controlling insect pests. Subasinghe and Fellowes (1978) has identified parasites of several grain legume pests in Sri Lanka including beanfly, bean pod borers, and corn ear worm, which damage mungbean. In the Philippines, incidence of natural parasites attacking grain legume pests is reported to be low (Litsinger, Price et al., 1978). However, in the southern U.S.A. pathogenic fungi are reported to inflict high mortality in populations of Lepidopterous larvae feeding on soybeans (National Science Foundation, 1974). Many of tre Lepidoptera that feed on soybeans also feed on mungbeans.

Increased utilization of natural control agents of insect pests would reduce costs associated with use of chemical insecticides and reduce the adverse effect on the environment accompanying the use of chemicals. Extensive research will be required before natural control agents can be manipulated so as to play a significant role in control of insects on mungbean and their use does not offer a viable alternative for the immediate future. Meanwhile, they should be observed, protected, and utilized as fully as possible as a component of an integrated pest management program.

(c) Chemical Control. Chemical insecticides offer a means of controlling local outbreaks of insect pests. Evidence that substantial yield increases may be obtained by use of chemical insecticides to control insect pests of mungbean is found in reports from Thailand (Sepswasdi and Moksongsee, 1971; Roonsook et al., 1973); the Philippines (Pablo and Pangga, 1971; Rejesus and Banasihan, 1978; Cruz, Paragna and Litsinger, 1980); India (Naresh and Thakur, 1972; Chowdhury et al., 1975; Saxena, 1978; Mahadevan et al., 1978), and Taiwan (AVRDC, 1978B, 1979). However, there is little information on the extent to which insecticides are used on mungbeans. In one survey in the Philippines (Litsinger et al., 1978), 41% of the farmers interviewed used insecticides and 84% practiced hand picking of large insects from mungbean. This may not be a typical sample since all of the farmers surveyed used insecticides on other crops. In most areas that mungbeans are grown, insecticides are seldom used on mungbean.

Recommendations for use of chemicals to control insects vary from country to country due to differences in insect pests present, availability of insecticides, availability of equipment to apply the insecticides, environmental consideration, and governmental regulatory procedures. A rational chemical control program for a particular area could be developed based on the following principles: (*a*) utilization of the most effective available insecticide that will control the insect pest, or complex of insect pests, with minimum damage to the environment; (*b*) optimum rate and timing of application, and (*c*) integration of chemical control with other pest control of insects may be uneconomical unless other good production practices are followed. Conversely, other practices may be uneconomical unless insect control is practiced in areas where insect damage is severe.

Rate and timing of insecticide applications are important, and will vary with type of insecticide being applied, insects to be controlled, and the environment (Rejesus and Banasihan, 1978). Studies in soybeans show that a moderate level of insect defoliation does not reduce seed yield (Hinson and Hartwig, 1977). The recommendation for soybeans is to delay application of the insecticide until defoliation approaches 35%. Frequently, natural control agents will then have reduced the insect pests so that insecticide use can be reduced or eliminated. Hinson and Hartwig (1977) suggest that application rates giving 80% kill of foliage feeding insects on soybean will be as effective in reducing crop injury as rates giving 100% kill. With the similarity of foliage feeding pests in soybean and mungbean, these recommendations should apply to mungbean as well as soybeans. The lower rate of application would reduce insecticide costs and cause less deterioration of the environment. The time of insecticide applications should be determined from specific information on kinds and number of insects present rather than stage of plant growth, or at predetermined intervals, as is often done (Rejesus and Banasihan, 1978). Excessive application of insecticides may injure or destroy the soil rhizobia and adversely affect nodulation. Chemicals alone should not be relied upon for complete pest control, but should be part of a total pest control program involving cultural practices, protection of natural predators, and use of resistant varieties, if they are available.

A partial list of insecticides and seed storage fumigants is given in Table 12. Some insecticides are sold under more than one trade name, and trade names in some countries may differ from those given here. All insecticides should be used strictly in accordance with the labeling. The label should be checked for crop to which the insecticide may be safely applied, insect pest to be controlled, and rate of application. Local regulations on the use of the chemical should be strictly adhered to, for the safety of the applicator and the consumer of the product. For example, Talekar, Lee, and Sun (1977) have shown that soil and foliar applications of ^{14}C labeled carbofuran and phorate were readily absorbed and translocated to plant tissue and to seeds of mungbean. Soil applications of granular fensulfothion in India left residues in mungbean seeds exceeding toxic tolerance levels; aldicarb and disulfoton residues were below tolerance levels (Rajukkannu et al., 1977). These experiments emphasize the need for careful monitoring of chemical applied and application procedures for safe use of an insecticide.

In the U.S.A., clearance by the Environmental Protection Agency (E.P.A.) is required before an insecticide can be labeled for use on a particular crop. None of the insecticides listed in Table 12 have E.P.A. clearance for use on

Table 12. Partial List of Systemic and Contact Insecticides and Fumigants.[a]

Common Name	Trade Name[b]	Nature of Compound	Toxicity to Humans
Aldicarb	Temik	Systemic carbamate insecticide, acaricide and nematacide	Very high
Carbaryl	Sevin	Carbamate insecticide	Moderate
Carbofuran	Suradan	Systemic insecticide and nematicide	Very high
Chlorpyrifos	Dursban, Lorsban	Organic phosphate insecticide	Moderate
Demeton	Systox	Systemic organic phosphate	Very high
Diazinon		Organic phosphate insecticide	Moderate
Dimethoate	Cygon, Rogor	Systemic organic phosphate	Moderate
Disulfoton	Di-Syston	Organic phosphate insecticide and acaricide	Very high
Endosulfan	Thiodan	Chlorinated hydrocarbon insecticide	High
Malathion		Organic phosphate insecticide	Low
Methoxychlor		Chlorinated hydrocarbon insecticide	Very low
Monocrotophos	Azodrin	Organic phosphate insecticide and acaricide	Very high
Nicotine sulfate		Contact insecticide	High
Oxydemeton-methyl	Meta-Systox R	Systemic phosphate insecticide and acaricide	High
Phorate	Thimet	Systemic organic insecticide and acaricide	Very high
Stirofos	Gardona, Rabon	Organic phosphate insecticide	Low
Terbufos	Counter	Organic phosphate, soil insecticide	Very high
Aluminum phosphide	Phostoxin	Fumigant for food grains	Very high
Carbon tetrachloride		Fumigant for food grains	Low
Methyl bromide		Fumigant for food grains	High

[a] Environmental protection and safety requires that all pesticides be used strictly in accordance with the labeling. Before using a pesticide the applicator should check the label for crop to which it may be applied, name of insect pest to be controlled, and dosage rate to be applied for a particular pest; and governmental regulations should be checked regarding use of the chemical on a particular crop and insect pest since they may vary in countries or provinces. None of the above chemicals have been registered by the Environmental Protection Agency for use on mungbean in the U.S.A.

Table 12. (continued)

[b]Trade names are used in this publication to provide specific information. Mention of a trade name does not constitute a warranty of the product by the University of Puerto Rico, the U.S. Agency for International Development, or the authors, or an endorsement over other products not mentioned. Pest control chemicals may be marketed under different trade names in different countries.

mungbean, although many have clearance for use on beans or soybeans. In part, the lack of clearance reflects the low market demand in the U.S.A. for insecticides to use on mungbean which has not justified the expense of testing insecticides to determine whether or not they will meet E.P.A. standards.

(d) Host Resistance. Varietal resistance to insects in mungbean has been studied at AVRDC. Screening tests have identified varietal resistance for the beanfly (AVRDC, 1974, 1975, 1978A, 1979), the cowpea aphid (AVRDC, 1979), and the *Callosobruchus* seed weevils (AVRDC, 1979). Litsinger, Quirino et al. (1978) suggest that priority in breeding for resistance be given to the flea beetle, leaf hopper, and beanfly because they are difficult to control by chemicals. Much additional research will be needed before resistant varieties make a significant contribution to reducing insect injury in mungbean.

XII QUALITY AND UTILIZATION

In many densely populated areas of the world, the food proteins consumed by man are largely of vegetable origin (Table 13). Cereal grains, due to the large amount consumed as human food, provide the major source of vegetable proteins. The grain legumes provide the next most important source. The daily protein intake supplied by the grain legumes varies from 2% in Northern Europe and 3% in Canada, to 26% in India (U.S.A.I.D., 1971; Jeswani, 1975). The uniqueness of the grain legumes as food is their high content of protein which nutritionally balances the protein from the cereal grains.

Table 13. Protein Consumption in Various World Regions.[a]

Region	Average Total Protein Consumed per Person per Day	Total Protein Supplied by			
		Cereal Grains	Grain Legumes	Animal Products	Other Sources
	g	%	%	%	%
<u>Developed Regions</u>					
North Europe	88	29	2	59	10
Canada	96	33	3	67	7
<u>Less Developed Regions</u>					
Central America and Caribbean	54	45	13	31	11
South America	57	40	10	36	14
India	56	57	26	13	4
Other South Asia	55	64	11	20	5

[a]Adapted from: United States Agency for International Development, 1971. Food Grain Legumes as a Major Means of Combating Malnutrition in LDC's. Technical Series Bulletin No. 5.

Nutritional Value of Mungbean

The nutritional constituents in dry seeds and sprouts of mungbean are compared with several grain legumes in Table 14. In most respects, the nutritional constituents of mungbean are comparable to those of dry beans, chickpea, and cowpea, but differ from those of soybean in protein, fat, carbohydrates, and some of the mineral elements.

Table 14. Nutritional Constituents in 100 Grams of Several Grain Legumes

Pulse	Water	Food Energy, Calories	Protein	Fat	Carbohydrates	Calcium	Phosphorus	Iron	Sodium	Potassium
	g		g	g	g	mg	mg	mg	mg	mg
Dry Seeds										
Mungbean	10.7	340	24.2	1.3	60.2	118	340	7.7	5.9	1027
Beans, white	10.9	339	22.3	1.6	61.2	144	425	7.8	18.9	1195
Chickpea	10.7	360	20.5	4.8	60.9	150	331	6.9	26.0	796
Cowpea	10.5	343	22.8	1.5	61.7	74	426	5.8	35.0	1023
Soybean	10.0	403	34.1	17.7	33.5	226	554	8.4	5.1	1676
Sprouts										
Mungbean	88.8	35	3.8	0.2	6.6	19	64	1.3	5.1	223
Soybean	86.3	46	6.2	1.4	5.3	48	67	1.0	-	-

[a]Adapted from: C. F. Adams. 1975. Nutritive Value of American Foods. United States Department of Agriculture, Agriculture Handbook 456.

Table 14. (continued)

Pulse	Vitamin A Value, International Units	Thiamin	Riboflavin	Niacin	Ascorbic Acid
		mg	mg	mg	mg
Mungbean	79	0.38	0.21	2.60	-
Beans, white	-	0.65	0.22	2.40	-
Chickpea	51	0.31	0.15	2.00	-
Cowpea	31	1.05	0.21	2.20	-
Soybean	79	1.10	0.31	2.20	-
Mungbean	20	0.13	0.13	0.79	18.9
Soybean	79	0.23	0.20	0.79	13.0

(a) Protein Content. The protein content of mungbean averages around 24%, roughly double the protein content of many cereal grains; similar to the protein content of dry bean, chickpea, and cowpea; and about two-thirds of the protein content of soybean. In sprouted seeds, the protein:carbohydrate ratio increases as the sprouting advances (Rochanapurananda, 1934).

(b) Amino Acid Balance. The amino acid content of mungbean and other pulses has been reported by Niyogi, Narayana, and Desai (1932); Vijayaraghavan and Srinivasan (1953), Bandemer and Evans (1963); Venkat Rao et al. (1964), Sevilla-Eusebio, Gonzales et al. (1968), Gonzales et al. (1972), Kylen and McCready (1975), and others. The specific content of the different amino acids in the protein of a particular species will vary with the variety and the environment in which it is grown, and the content reported may vary with the method of amino acid analysis. An average content for selected amino acids in several pulse and cereal grains is given in Table 15.

The nutritive value of mungbean protein is affected by the total protein content and the balance among the nutritionally essential amino acids. In animal proteins, the amino acids are generally present in proportions to satisfy human nutritional needs. In vegetable proteins, one or more amino acids is deficient so that the protein is not balanced as required for the human diet. The amino acids important in human nutrition which may be imbalanced in vegetable proteins are lysine, methionine, cystine, threonine, and tryptophan. A general rule is that the amino acids be supplied in the diet in a ratio of 4 parts lysine:2 parts methionine:2 parts threonine:1 part tryptophan. When an amino acid is so low in the total diet that the ratio is affected, it becomes the limiting factor in the nutritive value of the protein.

Mungbean and other pulse crops are relatively rich in lysine due both to high protein content in the seed and high content of lysine in the protein. Litzenberger (1973) reports that one gram of mungbean containing 19.3 mg lysine, compared to 3.74 mg in one gram of wheat and 2.99 mg in one gram of brown rice. Conversely, methionine and related sulfur-bearing amino acids are higher in cereal grains. One gram of wheat contains 5.28 mg combined methionine and cystine compared to 2.94 mg in one gram of mungbean. When cereal grains and mungbean are mixed in the diet, a better amino acid balance is possible than when either is consumed alone. A 70:30 ratio of rice protein to mungbean protein is suggested as being optimum for human diets (Florentino, 1974).

(c) Digestibility, Biological Value, and Nutritional Value of Mungbean Protein. Protein quality may be evaluated with reference to its digestibility and biological value. Mungbeans are widely regarded as being more easily digested than other pulses. For that reason it is a favorite pulse for elderly people and children. This belief is borne out by comparisons of several pulses which show digestibility values as follows: mungbeans, 83%; blackgram, 82%; chickpea, 76%; pigeon pea, 71% (Niyogi et al., 1932). Another measure of protein quality is biological value, which is the relation of protein retention to protein absorption. Comparative values for several pulses are as follows: mungbean, 64%; blackgram, 60%; chickpea, 78%; and

Table 15. Content of Several Amino Acids in Pulse and Cereal Grains.[a]

Crop		Lysine	Methionine	Cystine	Threonine	Tryptophan	Nutritive Value in Relation to Egg Protein
		mg	mg	mg	mg	mg	%
					Pulse Grains		
Mungbean:[b]	Average	504	33	44	209	50	32
	Range	419-678	24- 38	19- 65	186-225	35-102	
Bean:[b]	Average	450	66	53	248	63	47
	Range	306-557	28-131	21-108	192-356	32-101	
Chickpea:[b]	Average	428	65	74	235	54	53
	Range	406-463	34-106	50- 94	219-263	25- 94	
Cowpea:[b]	Average	427	76	68	225	68	57
	Range	394-479	50-119	48-106	178-300	66- 70	
Soybean:[b]	Average	399	79	83	241	80	62
	Range	313-477	53-114	51-114	200-285	75- 88	
Blackgram[c]		375	63		209	63	
					Cereal Grains		
Rice[d]	Average	200	100		169		76
Wheat[d]	Average	219	131		156		65

[a] Mg per g of nitrogen.

[b] USAID (1971), Tech. Bull. No. 5.

[c] Venkat Rao et al. (1964).

[d] Bandemer and Evans (1963).

cowpea, 72% (Niyogi et al., 1932). These data show the mungbean protein to be inferior to that of other pulses, except blackgram, in biological value. Comparisons at AVRDC show soybean protein to be slightly higher in digestibility than mungbean protein, and the two proteins to be similar in biological value (Tsou and Hsu, 1978). The nutritional value of mungbean protein is inferior to protein of other pulses and the cereal grains, rice and wheat, in comparisons with egg protein (Table 14). The nutritional value of egg protein as the standard is 100%. The low nutritional value of mungbean protein in comparison with egg protein results from deficiencies in the sulfur-bearing amino acids, methionine and cystine.

(*d*) Vitamins. Mungbean seed is a source of vitamin A, thiamin, riboflavin, niacin, and some other water soluble vitamins (Table 13). With sprouting, there is an increase in content of riboflavin, pyridoxine, niacin, pantothenic acid, and biotin (Burkholder and McVeigh, 1945). Ascorbic acid is synthesized in the sprouting process and sprouts provide a good source of this vitamin (Bhagvat and Rao, 1942; Kylen and McCready, 1975).

(*e*) Minerals. Mungbean seeds are a rich source of phosphorus, potassium, and iron, but are relatively low in calcium. The content of these mineral elements in mungbean is similar to that in bean, cowpea, and chickpea, but lower than in soybean (Table 13).

(*f*) Trypsin Inhibitor. The nutritive value of legume proteins is generally adversely affected by the presence of toxic substances such as trypsin inhibitor, hemagglutinins, or other growth inhibitors (Patwardhan, 1962; Liener, 1962; Venkat Rao et al., 1964). These substances exert a deleterious effect on growth by inhibiting the digestibility or utilization of particular amino acids including methionine. The adverse nutritional or toxic effect can be eliminated by appropriate methods of heating or cooking. A trypsin inhibitor has been isolated from mungbean seeds (Honavar and Sohonie, 1959), and digestibility of mungbean is improved by heating (Patwardhan, 1962; Sevilla-Eusebio, Mamaril et al., 1968). Mungbean and blackgram are reported to be low in toxic or antinutritional substances in comparison with other pulse grains (Engel, 1978). This appears to be borne out by research results cited by Venkat Rao et al. (1964), in which the weekly gain in body weight of rats fed autoclaved grain of mungbean and blackgram exceeded the gain of rats fed raw grain by 5% and 4%, respectively. In comparison, feeding autoclaved grain of cowpea and chickpea increased gains by 18% and 65%, respectively over feeding raw grains.

(*g*) Flatulence Factors. A characteristics of legume seeds consumed as food is their production of flatulence. The oligosaccharides, raffinose and stachyose, have been implicated as flatus producers. Mungbean is widely regarded to be low in production of flatulence in comparison with other pulse crops, or with soybeans. This is confirmed by reports which show a range in stachyose content in mungbean of 1.01 to 1.96 g/100 g of seeds and in soybean, 2.70 to 3.80 g/100 g seeds; and raffinose content in mungbean of 0.44 to 0.51 g/100 g seeds, and in soybean 1.25 to 1.30 g/100 g seeds (Tanusi, Kasai, and Kawamura, 1972; Tanaka et al., 1975; and Hymowitz, Collins, and Poehlman, 1975). Sprouts retain most of the flatulence factors of dry seeds (Calloway, Hickey, and Murphy, 1971). However, the dry weight of sprouts consumed is usually smaller than for seeds so that the flatus factors are ingested in relatively small amounts.

Utilization for Food

Mungbeans are utilized for food in many ways. Seeds may be eaten green with pods, cooked and used in soups, made into porridge, boiled and eaten with rice or other cereals, or sprouted. Starch from mungbean is used in making noodles. Mungbean flour is used to fortify wheat flour, or to produce high protein supplements for feeding children. Many indigenous dishes are prepared from mungbean.

(*a*) Milling. The largest producer of mungbean is India. In India, most of the mungbean is dehusked and split to produce a product locally known as *dahl*. The *dahl* is cooked in water and eaten with rice, or prepared in other ways. To produce the dehusked splits, or *dahl*, the mungbean may be milled by several procedures (Kurien, Desikachar, and Parpia, 1974; Araullo, 1974; Wrenshaw et al., 1974; United Nations University, 1979). In the traditional village milling process, the raw seeds are dried in the sun to loosen the husk. To assist in loosening the husk, the seeds may be treated with oil, or steeped for several hours in water, prior to drying. The husk is removed from the seed by pounding or grinding, after which the grain is winnowed to separate the husks from the cotyledons.

In commercial operations, the grain is dehusked by a roller mill, or an abrasion-type hulling machine, after the grain has been conditioned in a controlled temperature and moisture environment. The seeds may be split simultaneously with the husking process, or after being dehusked, using specially designed equipment. Removal of the hull decreases the fiber from 5% to 0.75% and increases protein from about 24% to 26% (Payumo, 1978).

The mungbean hull constitutes about 11% of the whole grain leaving a theoretical milling yield of 89%, but with the traditional milling procedures, milling loss is heavy and milling yields of 62% to 65% are common. With improved processing procedures, losses are reduced and milling yield can be increased to 83% (Kurien et al., 1974). Mungbean flour is produced from dehusked whole or split seeds.

(*b*) Cooking. Whole grains or splits of mungbean (*dahl*) are generally boiled after soaking in water for varying periods of time. In general, pulses require a long cooking time, from 30 to 40 minutes. The long cooking time is objectionable where fuel is scarce and expensive. For infant feeding, the bean must be mashed and sieved to remove the seed coat in addition. Mungbean is reported to require a shorter cooking period than other pulses. The cooking time required to obtain splitting of 50% of the seeds of several varieties of mungbeans at AVRDC averaged 22 minutes. Comparisons with other pulses were not made. Prior soaking in water increased the cooking time slightly. Blanching in boiling water for 4 minutes, with an 8-hour soaking period in salt water, reduced the cooking time to about 6 minutes (AVRDC, 1980). Many local Philippine recipes for preparation of mungbeans as food are given in the bulletin "The Philippines Recommends for Mungo, 1977" (PCARR, 1977).

(c) Starch. Mungbean starch noodle, a traditional Chinese food, is made from mungbean starch. It is tasteless, translucent, easily cooked, easily kept, and possesses a special texture. In comparisons of mungbean starch noodle with pea and sweet potato starch noodles, mungbean starch noodle was found to be excellent in texture by organoleptic test, to have much less cooking loss of solids, and to have a stronger structure as observed by scanning electron microscopy. This was thought due to the characteristic properties of mungbean starch, namely, stable paste viscosity at high temperatures, and amylose content (ca. 30%) which is optimum for production of a high quality starch noodle (Lii, Chen, and Wang, 1979). Mungbean starch is isolated commercially by a lactate fermentation, the so-called "wet process." This process results in high nutrient loss, especially protein, and disposal of the steeping liquor causes pollution problems (Wang, 1978; Chen, Wang, and Tsou, 1980). Studies are being made to improve the process.

(d) Supplemental Protein. Mungbean flour and protein isolates from mungbean are utilized to fortify many types of food products. In the Philippines, 80% of the preschool children are below the normal weight range, with nutritionally inadequate food during infancy and at weaning time being cited as the cause (Payumo, 1978). This has prompted the development of high protein food supplements from mungbean and other vegetable protein flours for use as weaning foods and for school feeding programs.

Several weaning foods have been formulated in the Philippines utilizing mungbean flour (Payumo, 1978). A mixture, called MCM, is made from mungbean and coconut flour and skim milk powder. Another, MRCF, is made from mungbean, rice and coconut flour, and fish protein concentrate. Both foods have a protein content around 24%, and contain 364 and 383 calories, respectively, per 100 g of food. A product, called Nutripac, is made from mungbean grits, rice, skim milk powder, and oil. Dried flakes are made utilizing mungbean flour with various combinations of rice flour protein isolate, fish protein concentrate, or dried milk. Other products utilizing mungbean flour include snack foods, cookies, coco noodles, and mungbean soup (Payumo, 1978; Payumo et al., 1969; Payumo and Castillo, 1979). A bread, *pan de sal*, is made by fortifying wheat flour with mungbean flour (Legaspi, Payumo, and Gopez, 1976). Protein isolates from mungbean, with a protein content of around 80%, may be used to fortify food products and increase their protein content (Gonzalez et al., 1964; Bhumiratana, 1978; Coffman and Garcia, 1978).

(e) Sprouting. Sprouted legume seeds have been used for centuries as a fresh vegetable in oriental cooking. In recent years they have become increasingly popular in the United States and Europe. Mungbean and blackgram are the principle legumes used in sprouting, although soybean may be used also.

Procedures for sprouting mungbean in the home have been described by Wen (1937), Beeskow (1943), Kuhn (1946), Bradsher and Upchurch (1980), and others. A simple home procedure is as follows: Soak the seeds overnight, or until the testa has burst. Place the swollen seeds in a canning kettle with a bottom rack and add water up to the level of the rack. Cover the rack with paper toweling, then alternate about three levels of seed and wet paper toweling. Store in a dark place at a temperature around 20 to 22°C. Sprinkle the towels sufficiently to keep them moist at all times. The sprouts should be ready to use in 5 to 7 days. Wash to remove the hulls. Procedures for commercial sprouting of large batches has been described by Kuhn (1946).

The nutrients in mungbean seeds and sprouts is reported by Adams (1975), Fordham, Wells, and Chen (1975), and Kylen and McCready (1975) (see Table 13). With sprouting, there is an increase in protein, thiamine, riboflavin, niacin, and ascorbic acid on a dry weight basis.

In commercial sprouting, a short, thick hypocotyl and short roots are preferred to long, spindly hypocotyls and long roots. When mungbean seeds are sprouted under stress, ethylene is produced which regulates growth in such a manner that sprouts with short roots and large diameter hypocotyls are produced (Chang, 1978). One method of applying stress is to apply pressure to the sprouting mungbeans. This can be done by placing a heavy weight on top of the mungbeans while they are sprouting. Temperature is important, also. Stouter roots were produced at 20°C than at 25°C, although roots were longer at the higher temperature. Another undesirable factor is anthocyanin formation. Anthocyanin formation in the sprouts is affected by the variety and is stimulated more at 25°C than at 20°C.

Blackgram is preferred to mungbean for sprouting in Japan. Sprouts from blackgram are reported to be whiter and stay fresh longer than sprouts from mungbeans. Small seeded soybeans are sprouted in mainland China.

Animal Feed

The forage remaining from mungbean after the pods have been picked has long been used for animal feed in India, the Philippines, and other Asian countries. Mungbean hay is comparable to hay from cowpea or soybean (Kingman and Doryland, 1917). Feeding trials in Oklahoma indicate that mungbean hay had 80% to 85% of the feeding value of alfalfa hay for milk production but was not eaten by dairy cows as well as alfalfa hay due to its coarse stems (Ronning et al., 1953). Palatability was improved by ensiling, with 2.85 kg mungbean silage being equivalent to 1 kg of alfalfa hay.

Cracked beans or mungbean seed otherwise unsuited for sprouting can be ground and used satisfactorily to partially replace protein concentrates in rations for dairy cows (Ronning et al., 1953), fattening lambs (Briggs and Heller, 1945), fattening swine (Thompson and Hillier, 1942), turkey poults (Milby, 1945), and poultry (Adan, 1935; Rodriguez, 1936; Thayer and Heller, 1949; Venkatraman and Jaya, 1976). Mungbean was high in palatability when compared with other legume seed in poultry rations, although not as palatable as animal proteins. Methionine must be supplied by other ingredients in the ration to overcome the deficiency in mungbean.

Utilization of mungbean seed in animal feed will usually be uneconomical except where it makes use of beans unsuited for human food.

Soil Improvement

Mungbean may be grown as a green manure crop to be plowed under, or as a combined cash and soil improvement crop with the residues turned under after pods have been harvested. Due to its short growth season, a large amount of vegetation is accumulated in a short period of time. Varieties that produce a large amount of growth would be most suitable for soil building. Inoculation to insure effective rhizobial activity will enhance its value as a soil building crop. Mungbean plants growing in Oklahoma contained 0.75% nitrogen in the roots, 1.48% in the stems, and 1.81% in the leaves (Ligon, 1945).

Breeding for Improved Quality

The unique feature of grain legumes from a nutritional standpoint is the high protein content of the seeds. Due to the high protein content, the grain legumes play a significant role in fortifying the protein content in the diets of people in many developing areas of the world. In breeding efforts to improve yield and nutritional quality, the pulses have been largely neglected and progress has been meagre in comparison with the extensive efforts and advancements that have been made with the cereal grains. This has resulted in a decline of total pulse production as hectares formerly planted to pulses have been shifted to the new, high yielding cereals. In recognition of this neglect, the Protein Advisory Group of the United Nations System has recommended development of a strategy for upgrading human nutrition through improvement of the food grain legumes.

Ranges in protein content from 23.6 to 34.0% for different varieties of mungbean were reported by Esh, De, and Basu (1959); from 19.8 to 23.1% by Krober et al. (1970); from 19.1 to 28.3% by Yohe and Poehlman (1972); and from 19.5 to 28.5% for 1845 accessions at AVRDC (AVRDC, 1975). A major problem in utilization of this information is that protein content is affected greatly by environmental factors such as soil fertility, soil moisture, temperature, plant disease, maturity of pod, and other factors. These data are usually reported from one analysis of a lot of seed grown at a single location. Unless a genetic strain is consistently higher in protein over a wide range of environments, one cannot be sure whether the differences are genetically controlled or artifacts of the environment. So far, solid evidence of the superiority in protein content of a particular genetic strain does not appear to be available, or if available, that high protein and high yield can be combined in the same strain. With the present state of breeding in mungbean, greater progress could be made by improving yield per hectare, thus increasing total protein production per hectare, than by efforts to improve the genetic potential for higher protein content.

The situation is similar for attempts to improve the amino acid balance. Mungbean is rich in lysine and deficient in methionine. Variation among genetic strains in methionine, and other amino acids, have been reported by Yohe and Poehlman (1972), Soni, Narang, and Singh (1975), Shobhana et al. (1976), and others. Blackgram is reported to have a higher methionine content than mungbean (Shobhana et al., 1976; Tsou et al., 1979). Methionine is generally reported as mg in one g of nitrogen. Thus environmental factors affecting protein content will also affect methionine content. There is insufficient data to show that a particular strain of mungbean is consistently high in methionine over a wide range of environments. Breeding efforts to increase methionine does not appear to be justified with the present state of mungbean breeding. Mungbean is not eaten as the sole food constitutient in a diet. It is generally eaten as a supplement to cereal products, which are comparatively rich in methionine. Increased total protein production through higher yields would increase total methionine production.

Short cooking time and large expansion in volume with cooking are desirable cooking characteristics in mungbean. Short cooking time is important as it would result in savings in fuel costs. Differences in cooking time and volume expansion with cooking of 60 varieties of mungbean were studied by Shivashankar et al. (1974). Cooking time varied from 29 to 55 minutes and volume increases of 100 to 312%, were reported among the 60 varieties. In general, small seeds had a higher specific gravity and gave maximum percentage increase in volume with cooking.

Mungbean protein was shown to have higher digestibility than blackgram protein at AVRDC, but was lower in methionine content (Tsou et al., 1979). Combining these characteristics through interspecific hybridization of the two species is being attempted.

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