8

The AVRDC Mungbean Improvement Program: The Past, Present and Future

G.C.J. Fernandez and S. Shanmugasundaram
Asian Vegetable Research and Development Center, P. O. Box 205, Taipei 10099

Abstract

AVRDC has been actively involved in a coordinated, multidisciplinary effort to improve mungbean during the past 15 years. The world's largest mungbean base collection is maintained at AVRDC. A majority of the collection has been evaluated for agronomic characters, nutritional components, and resistance or tolerance to the major pests and diseases. A modified bulk-pedigree breeding method, with disruptive seasonal selection, is commonly practiced to screen the segregating and advanced generations. The seasonal diversity of pests, diseases, photoperiod and thermal variation at AVRDC allows the effective selection for resistance/tolerance to various biotic and abiotic stresses. Annually, the selected breeding lines undergo a series of replicated yield trials both at AVRDC and in many parts of the world. AVRDC's mungbean program has accomplished the following: increased the yield potential of mungbean to about 2.7 t/ha from a low of 0.3 to 1 t/ha; developed resistance to Cercospora leaf spot and powdery mildew; bred new lines which are less photoperiod sensitive; synchronized maturity; improved plant-type with pods above the canopy; and improved tolerance to lodging and pod shattering. AVRDC lines have been officially released as new cultivars 25 times in 15 countries and a number of AVRDC accessions and breeding lines are currently being used by national mungbean breeding programs. The present and future strategies of the AVRDC mungbean improvement program are discussed.

Introduction

Mungbean is an ancient and well-known crop in Asia, particularly in the Indian Subcontinent, and is now becoming popular in other continents. It is an excellent source of easily-digestible protein of low flatulence, which complements the staple rice diet in Asia. Mungbean is consumed as *dahl*, bean sprouts, noodles, green beans, and boiled dry beans. Since it is a short-duration legume (maturing in 55 to 70 days), it fits well into many cropping systems, including rice and sugarcane, under rainfed and irrigated conditions, increases small farmers' incomes and improves soil conditions.

The Asian Vegetable Research and Development Center (AVRDC), the only international agricultural research center (IARC) working intensively on mungbean, has played an important role in mungbean improvement during the past decade. AVRDC scientists use a coordinated, multidisciplinary approach to solve the problems limiting mungbean production. During the past 15 years, AVRDC has made significant progress toward achieving many of the goals in mungbean improvement. The objectives, strategies, achievements and the future activities of the AVRDC mungbean improvement program are discussed below.

World Mungbean Production and Problems

An estimated total of 2.2 million t of mungbean and black gram combined are produced annually from approximately 5.8 million ha, of which a larger area is devoted to mungbean (Lawn and Ahn 1985). Annual world mungbean production is estimated at 1.4 million t harvested from about 3.4 million ha (Anon. 1984a). India produces 70% of this total world output (Shanmugasundaram and Poehlman 1988). Thailand, which exports about 40% of its total production, dominates the world mungbean trade (see also R.B. Singh and Chavalvut et al. in these Proceedings). It has also increased its production sixfold over the past 20 years so that it now ranks as the second major producer (Lawn and Ahn 1985). The United States annual mungbean production for sprouts is estimated to be 8.3 million kg (Lipton et al. 1981). Since each kilogram of seeds produces between 6 and 7 kg of sprouts, total production of bean sprouts in the USA probably amounts to at least 50 million kg annually (Lipton et al. 1981).

The low yield potential, lack of yield stability, susceptibility to major diseases and pests, narrow adaptability due to photoperiod and temperature sensitivity, susceptibility to abiotic stresses; nonsynchronous pod maturity, pod shattering and field weathering are the most serious production constraints of the local mungbean cultivars in the tropics. In addition, minimum management inputs also result in low yield.

AVRDC Mungbean Improvement Program Goals

The current goal of the mungbean improvement program is to develop stable, high-yielding mungbean lines with resistance to diseases and pests, uniform maturity and improved quality suitable for the tropics and subtropics.

Under the above broad goals, the following specific objectives are defined:

i) to develop stable, high-yielding (>2.0 t/ha), early- and uniformly-maturing, large-seeded cultivars;
ii) to incorporate reduced sensitivity to photoperiod and temperature variation;
iii) to develop advanced lines that are resistant to Cercospora leaf spot (CLS), powdery mildew (PM), viruses, beanfly, bruchid and pod borer;
iv) to develop tolerance to lodging, pod shattering, field weathering, drought and other stresses; and
v) to improve seed protein quality by increasing the methionine content through interspecific crosses.

In accomplishing the above objectives, advances have been made using various strategies and methodologies which are described below.

Breeding Methodology

The mungbean is predominantly a self-fertilizing species with about 4% to 5% natural outcrossing (Van Rheenen 1964). As germplasm is the foundation of crop improvement, AVRDC has been actively involved in mungbean germplasm activities such as collection, conservation, characterization, utilization and distribution. AVRDC was identified in 1981 and designated in 1983 by the International Board for Plant Genetic Resources (IBPGR) to hold the world mungbean base collection (IBPGR 1982, 1984).

Identification of superior pure lines, from locally available germplasm or from induced variation by hybridization or mutation is the primary objective in breeding self-pollinated crops. The superior lines are directly released as commercial cultivars by the national programs and/or further used as parents in breeding programs. Biparental, double, and multiple crosses are frequently made at AVRDC to obtain a wide spectrum of gene recombinations for quantitatively-inherited characters. AVRDC's mungbean program has made a total of 4,437 crosses from 1973 to 1986. The germplasm which were frequently used in the crosses are listed in Table 1.

Table 1. Mungbean germplasm frequently used in hybridization at AVRDC.

AVRDC acc no.	Name	Source	No. of times used as		%	Desirable character[z]
			Female parent	Male parent		
V 1301	PI 298915	China	0	1	0.23	–
V 2010	PI 298915	China	1	1	0.46	HY; MBCMV
V 1104	PI 164265	India	1	6	1.60	PM
V 1586	1-115-75 (LM 56)	India	0	2	0.46	–
V 1969	PI 223711	India	2	1	0.69	–
V 2272	PI 378038 (ML-5)	India	22	15	8.47	CLS; HY; PM
V 2273	PI 378039 (ML-6)	India	8	17	5.72	CLS;PM;HY;MYMV
V 2278	PI 425254 (ML-11)	India	1	0	0.23	–
V 2773	LM 689 (ML-3)	India	40	34	16.93	CLS; PM
V 2777	PI 425446 (ML-9)	India	1	0	0.23	–
V 3409	P 646	India	1	1	0.46	–
V 3726	Varsha (H 70-16)	India	1	0	0.23	HY; EM; PI
V 4718	PI 364100	India	0	2	0.46	CLS
V 5000	Shanhua 1 (from V 2773)	India	6	5	2.51	–
V 5200	15227	India	0	1	0.23	–
V 2007	EC 1521Q (M 304)	Korea, Rep. of	0	1	0.23	–
V 2984	Kyung-Ki Jaerae #5	Korea, Rep. of	0	1	0.23	HY; MBCMV; PDT
V 1066	Ph.Coll.01	Philippines	4	4	1.83	–
V 1067	Ph.Coll.02	Philippines	2	1	0.69	–
V 1377	EG-MG-12	Philippines	0	1	0.23	R
V 1378	CES-78	Philippines	0	4	0.92	–
V 1380	EG-MD-6D	Philippines	11	4	3.43	R; HY
V 1381	MG50-10A (G)	Philippines	4	6	2.29	HY; PI; UNI
V 1387	CES-55	Philippines	5	0	1.14	HY; BS
V 1394	EG-MG-4	Philippines	6	12	4.11	–
V 1400	EG-MG-16	Philippines	7	11	4.11	R
V 1411	CES-59	Philippines	14	9	5.26	–
V 1418	EG-MG-13	Philippines	1	0	0.23	R
V 1944	MG50-10A (Y)	Philippines	12	7	4.35	HY; PI; UNI
V 1945	BPI Glab. 3	Philippines	13	10	5.26	BS
V 1947	CES-44	Philippines	15	10	5.72	PDT; BS
V 1948	CES-87-17	Philippines	1	3	0.92	–
V 2184	PI 413539 (PHLV-18)	Philippines	9	27	8.24	HY; UNI
V 3476	Pag-asa 1 (CES 1D-21)	Philippines	17	20	8.47	HY; MBCMV; UNI; EM; PI; ERNL; NSH
V 6017	Pag-asa 2	Philippines	1	0	0.23	–
V 1476	Ujjainc 116	Sri Lanka	1	0	0.23	–
V 2013	Tainan #1	Taiwan, China	1	0	0.23	HY
V 2808	Local cultivar 1	Taiwan, China	1	0	0.23	HY
V 3686	MX3-1	USA	3	8	2.51	MBCMV
	Total		212	225	100%	

[z]PM = resistant to powdery mildew; R = general resistance to diseases; HY = high yield; PI = photoperiod insensitive; UNI = uniform maturity; PDT = possible drought tolerance; MBCMV = mungbean cucumber mosaic virus; CLS = Cercospora leaf spot; MYMV = mungbean yellow mosaic virus; EM = early maturity; ERNL = erect, nonlodging; NSH = nonshattering tendency at maturity; BS = big seeded.

Thousands of F_2 populations are annually screened for desirable traits in the field during three seasons, namely, spring (March-May), summer (July-September) and fall (September-November). Stringent elimination of undesirable genotypes is practiced in this generation. The

bulk population method is followed with selection for agronomic traits up to the F_5 generation. Pure line selection is practiced thereafter.

Photoperiod and temperature vary distinctly during the three seasons allowing disruptive seasonal selection to be practiced to identify breeding lines that are adapted to diverse agroclimatic conditions. The seasonal distribution of the mungbean pests and diseases also allows AVRDC scientists to screen effectively for resistance or tolerance to these pests and diseases through natural and artificial disease epiphytotics.

Backcross breeding and backcross-inbred methods (Wehrhahn and Allard 1965) are also currently being utilized to introduce specific traits, such as higher methionine level and tolerance to seed weathering, into desirable recurrent parents. The feasibility of mutation breeding is also being investigated with the tetraploid accessions, *V. glabrescens* (V 1160 or PI 207655) and MR 51 (amphidiploid between *V. radiata* x *V. umbellata*) to generate more variation and provide desirable mutants which may then be intercrossed. In collaboration with the Oregon State University, biotechnology methods such as embryo culture and anther culture are currently being utilized to accomplish the transfer of pest and disease-resistance genes from V 1160 into AVRDC mungbean cultivars.

In the pedigree or bulk population breeding methods for improving autogamous crops, selfing, following the initial cross, leads to rapid fixation of genotypes, thus precluding free exchange of favorable genes, restricting recombinations and, therefore, greatly limiting the desirable gene combinations (Joshi 1979). Following the diallel selective mating approach (Jensen 1970), intermating of selected F_2 progenies is currently being practiced at AVRDC to enable the accumulation of fixable components of genetic variability (additive and additive $\times$ additive gene effects) and breakage of unfavorable repulsion phase linkage effects.

Selected breeding lines are evaluated in replicated preliminary yield trials (PYT) during the spring, summer and fall seasons of the year. Selections from PYT are evaluated the following year for three seasons in intermediate yield trials (IYT). Promising entries from IYT are evaluated the following year in advanced yield trials (AYT). Mungbean lines selected from the AYTs are coded using *Vigna* cross numbers (e.g. VC 1973A, VC 2678A) and are evaluated during three seasons in elite yield trials (EYT).

The selected AVRDC breeding lines and superior mungbean accessions are evaluated annually in the international mungbean nursery (IMN) for adaptability and suitability in many countries. The first four IMN trials were conducted by the University of Missouri with financial support from USAID from 1971-75 (Morton et al. 1982). AVRDC has coordinated the IMN since 1976. The 15th IMN, which comprises 17 breeding lines and three accessions, is currently being distributed worldwide.

Improving Seed Yield and Stability

The per hectare average yield of mungbean in the tropics is deplorably low (only 0.4 t/ha, Anon. 1984b). Indeterminate growth habit, photoperiod sensitivity, late and nonsynchronous maturity, susceptibility to lodging, pod shattering, and losses due to pest and disease, are the major causes for the low-yield potential of the native mungbean cultivars.

Soil and environmental factors exert considerable influence on mungbean growth and production in the tropics. Mungbean is a warm-season crop (AVRDC 1981) and should be planted during the warm season to fully exploit its genetic potential.

The allelopathic effects of Chinese cabbage residue affect mungbean growth when planted after Chinese cabbage (Kuo et al. 1981). Poor growth and reduced seed yield were also observed in those soils previously cropped with soybean, tomatoes and mungbeans. However, mungbean following paddy wetland rice thrived and produced high yield (Ventura et al. 1984).

Breeding for improved plant type was emphasized initially to obtain high yield. The new improved plant type refers to a more compact plant with a higher harvest index, reduced photoperiod sensitivity, and more determinate growth habit than that of the older and more traditional

varieties (Shanmugasundaram and Poehlman 1988). New plant types are particularly suited to cropping systems in which mungbean is cultivated for short periods between major cereal crops.

With the development of improved plant type, the yield potential of AVRDC mungbean cultivars was increased from 0.3 to 1 t/ha to ca. 2.75 t/ha under a high plant population density of 400,000 plants/ha (Anon. 1984b). Sources for uniform maturity as well as resistance to pod shattering and lodging have been identified and successfully incorporated into breeding lines. Major efforts have also been devoted to reduce the time to maturity, to induce synchronous maturity, and to identify plant types with peduncles above the leaf canopy that facilitate easy harvesting (Anon. 1984a). Mungbean accessions with lobed leaflets (V 2773S) and multifoliate leaflets (V 5926) were also evaluated for their physiological merits (AVRDC 1981, AVRDC 1984).

Yield Stability

To provide information on the range of adaptability and genotype × environmental (GE) interaction, the IMN trials are conducted annually. Ahn et al. (1985) used the Eberhart and Russell (1966) method to evaluate the stability index of mungbean lines evaluated in the 9th and 10th IMN trials, separately. The estimated stability indexes were inconsistent between the 9th and 10th IMN and a positive linear relationship was observed between yield potential and stability index, which indicates that high-yielding lines showed below average stability.

The GE interaction and adaptability of the 7th to 10th IMN trials were studied using two-way classification analysis combined with analysis of variance and linear regression techniques (Imrie and Shanmugasundaram 1987). A large portion of yield variation was attributed to the environments (70-80%) while GE and genotypic contributions were small. However, since the genotypes tested and the trial sites have changed annually, only a restricted subset of genotypes and locations which were common from the 7th to the 10th IMN trials were included in this analysis. The genepool concept proposed by Pedersen et al. (1978) allows a comparison over years and sites, regardless of the specific entries used in a trial. As long as the entries under evaluation are representative samples of the population genepool, the entry mean across years can be used as the environmental index of a given site. Based on the genepool concept, assuming entries in an IMN as a representative sample of elite mungbean lines, the site mean was computed from the average of at least three IMN means evaluated in different years and used in the subsequent analysis.

A segmented regression analysis (Verma et al. 1978) was applied subsequently to detect entries which are high yielding, less sensitive to environmental fluctuation in unfavorable environments, but have the capacity to yield well in favorable environments. Thirty-one advanced breeding lines and superior accessions from the 5th to 12th IMNs were evaluated for environmental sensitivity and categorized into three groups, i.e. those suitable for (i) favorable environments only; (ii) high yield and stability under unfavorable environments; and (iii) better suitability to low-yielding environments. The mungbean lines representing the three groups are listed in Table 2. These groupings facilitate the recommendation of mungbean cultivars suitable for various agroclimatic regions.

Improved Environmental Adaptation

Reduced Photoperiod and Temperature Sensitivity

Photoperiod and temperature are important environmental factors that influence the phenological development of mungbean in all growth stages and, therefore, determine the adaptability of mungbean cultivars (Opeña et al. 1987). Mungbean is a short-day and warm-season crop (Aggarwal and Poehlman 1977). Although most mungbean lines flower in 12 to 13 h photoperiods, flowering is progressively delayed as the photoperiod is extended (Lawn

Table 2. Mungbean lines suitable for diverse environments based on environmental sensitivity analysis using segmented regression analysis.

Group A: High yielding but suitable for favorable environments only[z]	
	VC 1560D, VC 2565A, VC 2719A, VC 2755A, VC 2764A, VC 2768A, VC 2778A
Group B: High yielding but stable under unfavorable environments[y]	
	VC 1168B, VC 1209B, VC 1482C, VC 1562A, VC 1628A, VC 1973A, VC 1974A, VC 2523A, VC 2528A
Group C: Better suited under low-yielding environments[x]	
	VC 1089A, VC 1163A, VC 1168A, V 1381, V 1944

[z]Regression coefficients b_1 in low-yielding environment (El_1) and b_2 in high-yielding environment (El_2) are greater than 1. [y]$b_1 = 1$ in El_1 and $b_2 > 1$ in El_2. [x]$b_1 < 1$ in El_1 and $b_2 = 1$ in El_2.

and Ahn 1985, see also Summerfield and Lawn in these Proceedings). Generally, a higher mean temperature hastens flowering, and a lower mean temperature delays it at all photoperiods. Therefore, high-yielding cultivars with reduced sensitivity to photoperiod and temperature have less variability for time to flowering in a range of environments.

At AVRDC mungbean accessions and advanced breeding lines are screened for photoperiod responses in the field and in the greenhouse at a given temperature regime. The delay in flowering between natural photoperiod in the fall season (12 h) and the extended artificial photoperiod (16 h) is attributed to the photoperiod sensitivity of the lines. Photoperiod-insensitive accessions V 1400 (AVRDC 1979), V 1944 (AVRDC 1985), V 3726 (AVRDC 1986) and early- and uniform-maturing accessions V 6027, V 6037, V 6078, V 6080 and V 6083 (AVRDC 1984) were identified in the initial stages and were incorporated in the hybridization program. Selected high-yielding mungbean lines are evaluated in diverse environments in varying photoperiod and temperature regimes. AVRDC mungbean lines VC 1973A, VC 1628A, and VC 1168B possess reduced photoperiod sensitivity, as well as high yield and wide adaptability in diverse environments (AVRDC 1988).

Although reduced photoperiod-sensitive lines have been developed at AVRDC, a 7- to 20-day difference in flowering was observed in diverse locations where temperature and photoperiod ranged from 22 to 30°C and 11 h 45 min to 13 h 30 min, respectively.

The relationship between days to flowering (DF), mean photoperiod (P) and mean diurnal temperature (T) during the vegetative phase was quantified by the following quadratic response surface model:

$$E(DF) = 36.3 - 1.51\ t + 1.25\ p + 0.37\ t^2 + 4.56\ p^2 + 0.73\ tp\ (R^2 = 0.63),$$

where E (DF) = the expected days to flowering in 22 to 30°C and 11 h 45 min to 13 h 30 min temperature-photoperiod regimes; t = T-Tm; and p = P-Pm (Tm = 26°C and Pm = 12.5 h) are the overall temperature and photoperiod means, respectively.

The effect of mean temperature was more pronounced than that of the photoperiod in influencing flowering dates of AVRDC lines in these photothermal regimes. Only the linear effect and quadratic effects of temperature contributed to the variation in DF of reduced photoperiod-sensitive lines. The flowering was earliest at 34 days after planting when the mean temperature and photoperiod were 28.5°C and 12 h 15 min, respectively. Using this model, the flowering dates of AVRDC mungbean lines could be predicted within the specific range of temperature and photoperiod. Cool temperatures are generally not favorable for mungbean production. However, the mungbean accessions V 1484, V 2013, V 2164, V 1950, V 1398 and V 1250 were reported to be cold tolerant in the initial screening (AVRDC 1979).

The mungbean, a 60- to 70-day crop, is one of the promising candidates for crop diversification in rice-based agriculture. Therefore, maintaining the reduced photoperiod and temperature sensitivity in the newly-developed improved breeding lines is important.

Drought Tolerance

Drought stress is considered as one of the major limiting factors which contribute to instability and low productivity of mungbean. Severe drought reduces vegetative growth, flower initiation and pod set (Morton et al. 1982). The closure of stomata, due to lack of moisture, reduces photosynthesis, root extension and nutrient uptake. It also alters the level of endogenous plant hormones in stressed plants, which in turn may alter important physiological processes (Anon. 1984a). Therefore, screening genotypes for drought tolerance and incorporating the trait into high-yielding lines were emphasized initially at AVRDC. To screen genotypes for drought tolerance, mungbean accessions were subjected to 75-100 centibars soil-moisture tension for eight days from flowering (AVRDC 1979). Three accessions, V 2013, V 1281 and V 3372, were identified as drought tolerant and used in the breeding program.

In 1986 promising AVRDC breeding lines and accessions were assessed for drought tolerance based on several parameters under field and greenhouse conditions (AVRDC 1988). There was a general agreement between the greenhouse study and the field test. AVRDC breeding lines VC 1163D, VC 2750A, VC 2754A, and VC 2768A were selected as drought tolerant based on minimum reduction in yield, total dry matter and plant height in stressed, relative to non-stressed, treatment.

Flood Tolerance

Mungbean is not suited to the wet tropics where the annual precipitation is above 1,000 mm, because heavy rain and strong winds damage the mature crop causing severe yield loss. The reduced O_2 content in the soil atmosphere enhances flooding damage (Anon. 1984a). Based on the degree of plant survival, growth and yield after flooding, varietal differences for tolerance to flooding have been noted. Accessions V 1968, V 2984, V 3092 and V 3372 showed varying levels of tolerance to flooding (AVRDC 1979).

A prolonged rainy period at maturation often results in poor seed quality due to sprouting within the pods. Such premature sprouting is a serious problem in the tropics. The available resistance sources for field weathering are currently being confirmed at AVRDC. In addition AVRDC scientists are exploring the mungbean germplasm collection for additional sources for resistance to field weathering.

Improved Level of Pest and Disease Resistance

Pest Resistance

Insect pests attack mungbean from the seedling stage to maturity resulting in severe yield loss in the tropics. The most common insects are agromyzid beanflies (*Ophiomyia phaseoli* (Tryon), *O. centrosematis* (de Meijere), *Melanagromyza sojae* (Zehntner); pod borers and pod feeders (*Maruca testulalis* (Geyer) *Heliothis armigera* (Hb.); piercing and sucking insects (aphids and thrips) and storage pests — bruchids (*Callosobruchus chinensis* (L.) (see also Sehgal and Ujagir, Chhabra et al. in these Proceedings). Not all pests are serious at all locations; some are consistently found in large numbers, however, and are considered major pests. Although mixed cropping and crop rotation reduce pest populations of some species, it is not possible to obtain high yields unless combined with other protection measures (Morton et al. 1982). A warm and humid climate favors rapid insecticide degradation and enhances pest population buildup (Talekar and Chen 1983). A realistic control method is the integrated pest management using insect-resistant varieties in combination with minimal insecticidal application and good cultural control methods. At AVRDC identifying resistant or tolerant sources and utilizing them in the crop improvement program has been emphasized.

The peak population of beanfly in which there is up to 90% infestation, occurs in the late summer and fall seasons in Taiwan. Thousands of AVRDC mungbean germplasm accessions

have been screened for beanfly resistance or tolerance. Many sources with moderate levels of resistance were identified, incorporated into the advanced breeding lines, and are currently being evaluated for yield potential. The beanfly resistance mechanism in V 4281 was investigated and appears to be antibiosis (AVRDC 1986). An unusual wild *Vigna* species (V 1160, PI 207653), *V. glabrescens* was found to be immune to beanfly infestation (AVRDC 1986). Gene transfer from *V. glabrescens* to diploid mungbean is complicated by the tetraploid nature (2n = 44) of *V. glabrescens* in addition to interspecific differences. Collaborative research with the Oregon State University in the USA is underway to accomplish the transfer of pest resistance from *V. glabrescens* to *V. radiata* utilizing the currently-available biotechnology approaches.

Stink bugs, pod borers and pod feeders can cause direct damage to mungbean by feeding on the developing seeds in the pods. These insects have a wide host range and their damage varies among locations. Accessions V 2109, V 4270, V 2106 and V 2135 (AVRDC 1981) were identified as sources of resistance to pod borer (*Maruca testulalis*). The pod borer resistance mechanism is being investigated. AVRDC mungbean accessions, V 2184 and V 1381, were also reported to have resistance to cowpea aphids (AVRDC 1977).

Bruchids are a worldwide pest of mungbean in storage. The primary infestation, which causes only minor damage, begins in the field where larvae, concealed inside the pod, feed on developing seeds. After harvest when infested seeds are stored, the insect emerges to infest other seeds. Two black gram (*Vigna mungo*) accessions, VM 2011 and VM 2164, were found to be moderately resistant to bruchids. Crosses between black gram and mungbean were successful (AVRDC 1986). Screening is underway to select resistant lines from segregating populations. A high level of resistance was also recently found in *V. glabrescens*, and wild species *V. mungo* subsp. *silvestris*. Efforts are ongoing to incorporate the genes for resistance into the advanced breeding lines.

Disease Resistance

The mungbean is host to disease organisms such as fungi, virus and nematodes in the tropics. Several diseases, especially Cercospora leaf spot (CLS) (*C. canescens*, *C. cruenta*); powdery mildew (PM) (*Erysiphe polygoni*); mungbean yellow mosaic virus (MYMV); root disease complex (*Pythium* spp., *Rhizoctonia solani*, *Fusarium* spp.); and the reniform nematode (*Rotylenchulus reniformis*) and root-knot nematode (*Meloidogyne* spp.) can cause serious yield loss in mungbean (Morton et al. 1982). Cercospora leaf spot is more severe during the warm rainy seasons, while PM thrives in cool, dry weather. The root disease complex is favored by cool temperatures which retard mungbean growth. Certain crops preceding mungbean increase the nematode population in the soil and cause severe damage to mungbean. More than 20 different viruses have been reported to infect mungbean. The more common viruses are MYMV, black gram leaf crinkle and mungbean mottle virus (MMV) (Anon. 1984a). MYMV is transmitted by whiteflies (*Bemisia tabaci*), and appears to be severe in the Indian Subcontinent.

Potential yield losses caused by PM and CLS in mungbean were found to be higher than 40% and 58%, respectively (Shanmugasundaram and Tschanz 1987). The epidemiology of CLS has been studied and the yield loss due to CLS was estimated to be 10% in resistant cultivars (Anon. 1984a). Methodology and culture medium for the propagation of *C. canescens* inoculum and the techniques for the inoculation were developed (Mew et al. 1975). Resistant sources for CLS and PM were identified from thousands of mungbean germplasm accessions at AVRDC, and successfully incorporated into advanced breeding lines (Table 3). Several breeding lines which are more resistant than their resistant parents have been developed. In 1978 the close association of PM resistance with small seed and photoperiod sensitivity was broken, leading to the development of AVRDC breeding lines VC 1560C and VC 1482A. Advanced breeding lines with high-yield potential, combined with CLS and PM resistance, have also been developed (Table 4).

MYMV is not prevalent at AVRDC. However, several viruses have been isolated from mungbean at AVRDC and at Pingtung, Taiwan. They cause mottling, mosaic and leaf crinkle symptoms (Anon. 1984a). One of these viruses is seed-transmitted and is serologically related to cucumber mosaic virus (CMV). The host range was found to be largely confined to the legume

family. Resistant breeding lines (VC 2755A, VC 1973A) and accessions (V 2010, V 2984) have been identified (AVRDC 1987). The resistance may be due to hypersensitivity as it seems to be associated with the appearance of necrotic local lesions on the inoculated leaves.

Table 3. AVRDC mungbean accessions and breeding lines with high level of resistance to CLS and/or PM.

Lines[z]	Name/Pedigree
	Cercospora leaf spot
V 2773[y]	ML-3
V 4718[y]	PLM 945
V 5000	Shanhua 1
VC 1137A	Tainan 1//ML-6//EG-MG-16/ML-3
VC 1560D	BPI Glab. 3//CES-44/ML-3
VC 2720A	Shanhua 1//CES-59/ML-5
VC 3689A	ML-3/Ph.Coll.1// /MG50-10A (Y)/ML-5/// PLM 945
VC 3543A[y]	VC 1089A/VC 1177A//VC 1168A/VC 1089A
VC 3741A	VC 1209C × VC 2764A
	Powdery mildew
V 2773	ML-3
V 4718	PLM 945
VC 1560A	BPI Glab. 3//CES-44/ML-3
VC 1560C	BPI Glab. 3//CES-44/ML-3
VC 1482A	EG-MD-60/ML-3
VC 3528A	BPI Glab. 3/VC 1301//ML-3/CES 1D-21
VC 3543A	VC 1089A/VC 1177A//VC 1168A/VC 1089A

[z]The VC lines are products of the AVRDC mungbean improvement program. [y]Resistant to both diseases.

Table 4. New elite lines with high-yield potential and high levels of resistance to both CLS and PM.

Line	Yield (t/ha)[z]		First harvest (%)		Days to maturity		1000-seed[y]
	spring	summer	spring	summer	spring	summmer	weight (g)
VC 3528A	2.4	1.7	43	84	66	59	62
VC 3543A	2.7	1.1	41	71	69	60	61
VC 3741A	2.9	2.1	58	68	71	63	50
VC 3689A	2.2	1.3	65	88	72	63	48
V 3476[x]	1.9	1.4	51	83	65	60	58

[z]Yield data from 1984. [y]Fall season. [x]Susceptible check.

A new poty virus has recently been isolated from mungbean in Taiwan. The virus is serologically closely related to blackeye cowpea mosaic virus (BLCMV), adzuki bean mosaic virus (AzMV) and the NY-15 strain of bean common mosaic virus (BCMV) (AVRDC 1986). The virus was found to be aphid-transmitted. A significant yield reduction occurred in mungbean when plants were infected at the early growth stage. Resistance was not detected in elite breeding lines; however, immunity was found in the following accessions: V 1682, V 1153 and V 1745 (AVRDC 1987). On the basis of the wide host range, seed transmissibility and absence of resistance to this virus in the advanced breeding lines, breeding for resistance to the above viruses needs to be emphasized in the future. Resistance sources to other mungbean diseases are presented in Table 5.

Quality Improvement

High-yielding cultivars may not always give the farmer the highest profit. Local preference, market price and rate of return to additional increments of management input should be taken into

Table 5. Reported resistance sources to mungbean diseases.

Disease	Name	AVRDC acc.	Source
Damping-off	OB 24-1	V 4993	AVRDC 1977
(*Rhizoctonia solani* Kuhn)	STB-29	V 1446	AVRDC 1978
Charcoal rot	Uthong 1	V 3404	AVRDC 1981[z]
(*Macrophomina phaseolina*)	Pag-asa 1	V 3476	AVRDC 1981
(Tasso) Goid	6601	V 3484	AVRDC 1981
Bacterial leaf spot (*Xanthomonas campestris* pv. *phaseoli* (Smith) Dye)	CQ 30067	V 2165	AVRDC 1974
Root-knot nematode	CES-07	V 1412	AVRDC 1979
(*Meloidogyne incognita*	LM 170	V 1709	AVRDC 1979
(Kofoid & White) Chitwood)	PI 298915	V 2010	AVRDC 1979
	ML-3	V 2773	AVRDC 1979
	PI 180313	V 1133	AVRDC 1981
	PHLV-13	V 2179	AVRDC 1981
	LM 517	V 2744	AVRDC 1981
Mungbean yellow mosaic virus	ML-3	V 2773	AVRDC 1978[y]
	ML-5	V 2272	AVRDC 1978
	6601	V 3484	AVRDC 1978
	PAK 22	V 3485	AVRDC 1978
	71-17	V 3486	AVRDC 1978
	No. 122	V 3417	AVRDC 1981[x]
	PLM 618	V 4483	AVRDC 1981[x]
	ML-1	V 2772	AVRDC 1986[w]
	Type-1	V 4800	AVRDC 1986

[z]Reported in Sri Lanka. [y]Reported in Bangladesh. [x]Reported in India. [w]Reported in Pakistan.

account. Location-specific factors such as seed size, seed coat color and luster influence consumer preferences. In many places, green, shiny and large seeds are preferred to other types. The quality characteristics and consumer preferences for mungbean seeds have been considered in the AVRDC mungbean improvement program and many elite lines, with a wide range of seed characteristics, have consequently been developed.

The mungbean is rich in easily-digestible protein, but it lacks the essential sulfur-containing amino acids, methionine and cysteine, thereby limiting its protein quality (Tsou et al. 1979). The chemical score of mungbean is about 32% that of egg protein, or 40% of the FAO provisional pattern and is lower than values for most legumes (Tsou et al. 1979). It appears that the nutritional quality of mungbean can be improved by increasing its available methionine content without affecting its digestibility.

The results of studies to determine the methionine content in mungbean germplasm through microbiological assay showed that there was a narrow variability for available methionine content (Tsou et al. 1979). However, the closely-related species *V. mungo* and its wild ancestor *V. mungo* subsp. *silvestris* contain very high levels of available methionine (AVRDC 1987). Further studies indicated that methionine content is governed by polygenes (AVRDC 1987). Crosses between mungbean and *V. mungo* subsp. *silvestris* accessions (TC 2208, TC 2209, TC 2210, TC 2211) have been made and the subsequent derivatives showed higher levels of free methionine and γ-glutamyl-methionine than mungbean (AVRDC 1987). Currently, backcross-inbred populations are being derived between the mungbean $\times$ *silvestris* progeny which will be evaluated for desirable agronomic characters and level of methionine content.

Achievements and Future Prospects

The AVRDC mungbean improvement program has made a significant contribution to worldwide mungbean production in the past decade. The yield potential of mungbean has been

improved to about 2.7 t/ha, and in the experimental field from 0.3 to 1 t/ha. Plant architecture has been changed, resistance to CLS and PM has been incorporated into advanced lines, pod maturity has reached 80% at first harvest, and plants are now less sensitive to photoperiod than before. Thousands of seed samples from AVRDC have been distributed worldwide. As of October 1987, 27 cultivars have been officially released in 15 countries, directly or indirectly from the AVRDC improvement program (Table 6).

In addition of high-yield potential, better and stable sources of resistance or tolerance to certain major pests, diseases and enviromental stresses will be further explored. Maintaining the reduced photoperiod sensitivity and improving the level of temperature sensitivity in the new

Table 6. AVRDC mungbean officially released by cooperating nation, Nov. 1987.

Local Name	AVRDC ID #	Year	Country	Remarks[z]
	VC 1560D*	1982	Australia	
King	V 1388*	1982	Australia	HY, EM, PW, LD
Xu Yin No.1	VC 1973A	1985	China	HY, WA
ASVEG 78	VC 1089A	1978	Costa Rica	HY
INIAP 451	VC 1163	1985	Ecuador	PW, HY, TV, M/MH
Station 46	VC 1000-45-B	1982	Fiji	HY
Station 25	VC 1007-14-1-5-B	1984	Fiji**	
Station 27	VC 1160-1-1-2-B	1984	Fiji**	
M 986		1981	India*	
Pusa 101	V 3484* or VC 2125*	–	India*	(CLS), MYMV, HY, WA, LS
Pusa 105	VC 1137-2-B	–	India*	(CLS), MYMB, HY, WA, LS
Manyar	VC 1089A	1983	Indonesia	HY, CLS, R
Nuri	V 2773	1983	Indonesia	HY, (CLS), R
Walet	VC 1163A	1986	Indonesia	HY, NS, CLS, RPM, TDO, UM
Gelatik	VC 1160-22-2B-1-B	1986	Indonesia	HY, NS, CLS, RPM, UM
Bangasa	V 3476	1980	Korea, Rep. of	HY, UM, LD
Seon Hwan Ogdu	VC 1973A	1982	Korea, Rep. of	HY, MMV, RPM, (CLS),UM
		1983	Malaysia**	
BPI Mg2	VC 1163	1984	Philippines	HY, CLS, RPM, R
BPI Mg4	VC 2764B	1986	Philippines	HY, UM, LD, EM, (CLS), (RPM)
Type-77	VC 1131-B-12-2-B	1982	Sri Lanka	HY, MYMV, CR
Filsan	VC 1168B	1987	Somalia	NS, EM
Tainan Sel.#3	VC 1628A	1981	Taiwan	HY, UM, LD
Imara	V 1380	1983	Tanzania	
KPS No.1	VC 1973A	1985	Thailand	
KPS No.2	VC 2778A	1985	Thailand	
Chai Nat 60	VC 1178	1987	Thailand	EY, EM, RCS, UM
DX 102a	VC 2768A	1986	Vietnam	HY, SLS-R, RLD
DX 113	VC 2763A	1986	Vietnam	HY, TASS, RLD
DX 91	VC 1560D	1986	Vietnam**	

*Adapted line bred from AVRDC parental stocks.
**Reported release but no additional information available.
[z]CLS : Resistant to Cercospora leaf spot, parentheses indicate moderate levels of resistance
CR = Resistant to charcoal rot
DR = Drought resistant
EM = Early maturing
FR = Flood resistant
HY = High yield
MMV = Resistant to mungbean mottle virus
NS = Nonshattering
QCS = Suitable for rice-based cropping system
R = Rust resistant
M/MH = Manual/mechanical harvesting
RPM/RTM = Resistant or tolerant to powdery mildew
MYMV = Resistant to mungbean yellow mosaic virus
TASS = Tolerant to acidic and saline soils
PW = Resistant to pod weathering
WA = Wide adaptability
RLD = Resistant to local disease
UM = Uniformly maturing
SLS-R = Sandy loam soil after rice
TDO = Tolerance to damping-off
TV = Tolerant to viruses

elite breeding lines will be continuously emphasized. The drought-tolerant elite breeding lines will be further evaluated in locations where drought is the major limiting factor. The flood tolerance mechanism needs to be elucidated. Significant progress in disease resistance breeding at AVRDC resulted in the development of high-yielding CLS- and PM-resistant cultivars in the past. Efforts to incorporate early and uniform maturity in the above-mentioned lines need to be emphasized. The stability of disease resistance will be monitored in the IMN. The inheritance and breeding for resistance to CMV and the new poty virus will be emphasized. Sources of resistance to field weathering are yet to be confirmed or found. Seasonal influences on synchronous maturity needs further study to fully understand its nature. Interrelationships between crop maturity and disease resistance needs additional investigation. Combining the desirable traits into high-yielding and widely-adaptable lines will still be the major emphasis in the future.

Some important insect problems are not readily solved through conventional intraspecific hybridization. More use of interspecific crosses and application of biotechnological methods will be explored. Feedback information on released cultivars in many national programs will be utilized to restructure the AVRDC mungbean improvement program, to diversify the breeding objectives, and to serve the needs of mungbean growers and consumers throughout the world.

Significant progress in disease resistance breeding at AVRDC resulted in the development of high-yielding, CLS- and PM-resistant cultivars in the past. Efforts to incorporate early and uniform maturity in the above lines will be emphasized in the future. The stability of disease resistance will be monitored in the international mungbean nursery. Diverse germplasm resources and wild species will be screened for higher levels of resistance, and will be incorporated, if available, into future breeding lines.

Literature Cited

Aggarwal, V.D. and J.M. Poehlman. 1977. Effects of photoperiod and temperature on flowering in mungbean. Euphytica 26:207-219.

Ahn, C.S., J.H. Chen and H.K. Chen. 1985. Performance of the ninth (1981) and tenth (1983) IMN. Asian Vegetable Research and Development Center, Shanhua, Tainan. 86 p.

Anon. 1984a. AVRDC organization and plans. Asian Vegetable Research and Development Center, Shanhua, Tainan. 405 p.

Anon. 1984b. Report of the Third External Review of the Asian Research and Development Center (AVRDC), Shanhua, Tainan. 176 p.

AVRDC. 1974. Annual Report for 1972-1973. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 52 p.

AVRDC. 1977. AVRDC Progress Report 1976. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 77 p.

AVRDC. 1978. AVRDC Progress Report 1977. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 90 p.

AVRDC. 1979. AVRDC Progress Report 1978. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 173 p.

AVRDC 1981. AVRDC Progress Report 1979. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 107 p.

AVRDC 1984. AVRDC Progress Report 1982. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 337 p.

AVRDC 1985. AVRDC Progress Report 1983. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 444 p.

AVRDC. 1986. AVRDC Progress 1984. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 480 p.

AVRDC. 1987. AVRDC Progress Report 1985. Asian Vegetable Research and Development Center (AVRDC), Shanhua, Tainan. 471 p.

AVRDC. 1988. AVRDC Progress Report 1986. Asian Vegetable Research and Development

Center (AVRDC), Shanhua, Tainan. (In press.)
Eberhart, S.A. and W.A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.
IBPGR. 1982. Genetic resources of *Vigna* species. International Board for Plant Genetic Resources (IBPGR), Rome. 18 p.
IBPGR. 1984. Annual Report 1983. International Board for Plant Genetic Resources (IBPGR), Rome. 126 p.
Imrie, B.C. and S. Shanmugasundaram. 1987. Source of variation for yield in international mungbean trials. Field Crops Res. 16:197-208.
Jensen, N.P. 1970. A diallel selective mating system for cereal breeding. Crop Sci. 10:629-633.
Joshi, A.B. 1979. Breeding methodology for autogamous crops. Indian J. Genet. Plant Breed. 39(3):567-568.
Kuo, C.G., M.H. Chou and H.G. Park. 1981. Effect of Chinese cabbage residue on mungbean. Plant Soil 61:473-477.
Lawn, R.J. and C.S. Ahn. 1985. Mungbean (*Vigna radiata* (L.) Wilczek/*Vigna mungo* (L.) Hepper. Pages 584-623. *In* R.J. Summerfield and E.H. Roberts, eds. Grain Legume Crops. Collins, London.
Lipton, W.J., W.K. Asai and D.C. Fouse. 1981. Deterioration of CO_2 and ethylene production of stored mungbean sprouts. J. Am. Soc. Hortic. Sci. 106(6):817-820.
Mew I-Pin C., T.C. Wang and T.W. Mew. 1975. Inoculum production and evaluation of mungbean varieties for resistance to *Cercospora canescens*. Plant Dis. Rep. 59:397-401.
Morton, F., R.E. Smith and J.M. Poehlman. 1982. The Mungbean. University of Puerto Rico, Mayaguez. 136 p.
Opeña, R.T., S. Shanmugasundaram, J.Y. Yoon and G.C.J. Fernandez. 1987. Crop improvement program to promote vegetable production in the tropics. Pages 1-17. *In* W.N. Chang, R.T. Opeña and J. B. Patersen, eds. The Breeding of Horticultural Crops. Food and Fertilizer Technology Center for the Asian and Pacific Region. Taipei. Taiwan.
Pedersen, A.R., C.H. Everson and J.E. Grafius. 1978. The gene pool concept as a basis for cultivar selection and recommendation. Crop Sci. 18:683-686.
Shanmugasundaram, S. and J.M. Poehlman. 1988. Genetics and breeding of mungbean. *In* A.K. Mandal, ed. Genetics, Cytogenetics and Breeding of Crops. (In press.)
Shanmugasundaram, S. and A.T. Tschanz. 1987. Breeding for mungbean and soybean disease resistance. *In* Proceedings of Symposium on Varietal Improvement of Upland Crops for Rice-Based Farming Systems, IRRI, Los Baños. (In press.)
Talekar, N.S. and B.S. Chen. 1983. Seasonality of insect pests of soybean and mungbean in Taiwan. J. Econ. Entomol. 76(1):34-37.
Tsou, C.S., M.S. Hsu, S.T. Tan and H.G. Park. 1979. The protein quality of mungbean and its improvement. Acta Hortic 93:279-287.
Van Rheenen, H.A. 1964. Preliminary study of natural cross-fertilization in mungbean. Neth. J. Agric. Sci. 12(4):260-262.
Ventura, W., I. Watanabe, H. Komada, M. Nishio, A. De La Cruz and M. Castillo. 1984. Soil sickness caused by continuous cropping of upland rice, mungbean, and other crops. IRRI Research Paper Series No. 99, Manila. 13 p.
Verma, M.M., G.S. Chahal and B.R. Murty. 1978. Limitations of conventional regression analysis a proposed modification. Theor. Appl. Genet. 53:89-91.
Wehrhahn, C. and R.W. Allard. 1985. The detection and measurement of the effects of the individual genes involved in the inheritance of a quantitative character in wheat. Genetics 51:109-119.