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The Mungbean Transformation

Diversifying Crops, Defeating Malnutrition

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MILLIONS FED

"Millions Fed: Proven Successes in Agricultural Development" is a project led by IFPRI and its 2020 Vision Initiative to identify interventions in agricultural development that have substantially reduced hunger and poverty; to document evidence about where, when, and why these interventions succeeded; to learn about the key drivers and factors underlying success; and to share lessons to help inform better policy and investment decisions in the future.

A total of 20 case studies are included in this project, each one based on a synthesis of the peer-reviewed literature, along with other relevant knowledge, that documents an intervention's impact on hunger and malnutrition and the pathways to food security. All these studies were in turn peer reviewed by both the Millions Fed project and IFPRI's independent Publications Review Committee.

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Notices

[1] Effective January 2007, the Discussion Paper series within each division and the Director General's Office of IFPRI were merged into one IFPRI–wide Discussion Paper series. The new series begins with number 00689, reflecting the prior publication of 688 discussion papers within the dispersed series. The earlier series are available on IFPRI's website at www.ifpri.org/pubs/otherpubs.htm#dp.

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ABSTRACT

Mungbean is a major pulse crop in Asia. National partners in Bangladesh, Bhutan, China, India, Myanmar, Nepal, Pakistan, Sri Lanka, and Thailand collaborated with AVRDC – The World Vegetable Center, using an integrated, interdisciplinary approach to research and develop improved mungbean varieties and technologies. The effort aimed to resolve the major constraints limiting mungbean production and resulted in the release of improved varieties with traits such as short maturity duration, high yields, and disease resistance to *Cercospora* leaf spot, powdery mildew, and *Mungbean yellow mosaic virus*. The total area planted to improved varieties has reached almost 3 million hectares across these countries, providing an estimated 1.5 million farmers with yield increases of about 300 kilograms per hectare. In terms of consumption, mungbean consumption has increased 22 to 66 percent in the various countries, and has been demonstrated to improve the health of anemic women and children. This paper traces the research, development, and dissemination of improved mungbean in Asia and examines its impact on agricultural productivity and food security. Actions to sustain the intervention and support future research are noted.

Keywords: Millions Fed, Food Security, Mungbean, AVRDC, World Vegetable Center, Asia

1. INTRODUCTION

Background

Mungbean, *Vigna radiata* var. *radiata* (L.) Wilczek, is one of the major pulse crops supplementing the cereal-based diet of the poor in Asia today. High in protein and easy to digest, mungbean consumed in combination with cereals can significantly increase the quality of protein in a meal (Thirumaran and Seralathan 1988). Yet 30 years ago, mungbean was still a crop relegated to marginal lands and cultivated with minimal inputs.

Beginning in the 1960s, cereals were the focus of agricultural research in Asia; cereal production increased, and Asia attained sufficiency in food energy (ESCAP 1985). However, the issue of protein-calorie malnutrition remained unresolved in developing countries (FAO 1985). The emphasis on cereal production pushed legumes, including mungbean, to more marginal environments (Wallis and Byth 1988; Singh 1988). Legume production during this period was either stagnant or decreasing, justifying the title of "slow runners" (Borlaug 1973). Continuous cereal production depleted water tables and led to soil salinization; the incidence of cereal pests and diseases increased; and greater amounts of pesticides were used for control, polluting the environment and harming human health (Evenson and Gollin 2003; Sekhon et al. 2007)

Traditional mungbean cultivars grown in Asia reached maturity in 90–110 days. These indeterminate cultivars were susceptible to diseases, especially Mungbean yellow mosaic virus (MYMV) and insects. Farmers had to harvest multiple times; pod shattering was a problem; and the labor-intensive, low-yielding cultivars produced only about 400 kilograms (kg) per hectare (ha) of small seed. The World Vegetable Center (AVRDC), an international agricultural research institute based in Taiwan, recognized the potential of mungbean to supply protein to Asia's hungry, to provide farmers with an income-generating opportunity, and to diversify agro-ecosystems—if the pulse could fit into high-yielding cereal cropping systems (Shanmugasundaram 2006). As proposed by Borlaug (1973), AVRDC launched a holistic mungbean improvement program to improve productivity and production.

Intervention

The mungbean intervention highlighted in this report was focused on Bangladesh, Bhutan, China, India, Nepal, Myanmar, Pakistan, Sri Lanka, and Thailand. The foundation of the intervention was laid as early as 1972; however, the specific components of the initial project did not commence at AVRDC until April 1997, with financial support from the Department for International Development (DFID) of the United Kingdom. The mungbean effort continues today with support from various agencies.

The project had two phases: (1) "Promotion of Mungbean Research Outputs for Farmer Adoption in South Asia" (DFID's holdback project from April 1997–March 2001); and(2) "Improving Income and Nutrition by Incorporating Mungbean in Cereal Fallows in the Indo-Gangetic Plains of South Asia" (DFID project, March 2002–May 2004). The intervention included key players from across Asia (Table 1).

Table 1. Intervention's stakeholders

Area	Organization
Pan-Asia	• AVRDC – The World Vegetable Center • AVRDC Asian Regional Center (ARC) • AVRDC Regional Center for South Asia (RCSA)
China	• Chinese Academy of Agricultural Sciences
Bangladesh	• Bangladesh Agricultural Research Council (BARC) • Bangladesh Agricultural Research Institute (BARI) • Bangabandhu Sheik Mujibur Rahman Agricultural University (BSMRAU) • AVRDC–USAID Bangladesh Project
Bhutan	• Agricultural Department, Government of Bhutan
India	• Indian Council of Agricultural Research (ICAR) • Indian Agricultural Research Institute (IARI) • Indian Institute of Pulses Research (IIPR), Kanpur • Punjab Agricultural University (PAU), Ludhiana • G. B. Pant University of Agriculture and Technology (GBPUAT), Pantnagar • CCS Haryana Agricultural University, Hisar • Tamil Nadu Agricultural University (TNAU), Coimbatore • Rajasthan Agricultural University, Sriganganagar, Rajasthan • Avinashilingam Deemed Home Science University for Women, Coimbatore
Myanmar	• International Rice Research Institute (IRRI), Food and Agriculture Organization of the United Nations (FAO) office
Nepal	• Nepal Agricultural Research Council (NARC) • Forum for Rural Welfare and Agricultural Reform for Development (FORWARD) • Local Initiatives for Biodiversity Research and Development (LI-BIRD) • National Grain Legume Research Program • International Maize and Wheat Improvement Center (CIMMYT) office
Pakistan	• Pakistan Agricultural Research Council (PARC) • National Research Center, Islamabad • Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad • Ayub Agricultural Research Institute
Sri Lanka	• Field Crops Research and Development Institute, Maha Illuppallama, • Department of Agriculture, Sri Lanka
Thailand	• Department of Agriculture • Department of Agricultural Extension • Kasetsart University • Prince Songkla University • Khon Kaen University

The strategic pathway to the mungbean transformation began by collecting germplasm with sufficient genetic diversity to select the needed traits, identifying the specific traits to accomplish the objectives, and breeding the traits into improved lines. The Center's gene bank, home to one of the world's largest mungbean germplasm collections, provided the genetic material for breeders.

Early on it was decided that the necessary traits were high yield, bold seeds, wide adaptation, early and synchronous maturity, and resistance to the most important diseases: Cercospora leaf spot and powdery mildew for Southeast and East Asia, including China, and MYMV for South Asia. Among the insect pests, mungbean weevil (*Callosobruchus chinensis*) was a major focus (Fernandez and Shanmugasundaram 1988).

The South Asia Vegetable Research Network (SAVERNET) was established to facilitate the organization, planning, training, and implementation of the master work plan. A uniform evaluation procedure for all the countries and institutions was developed and the improved seeds were provided to all institutions; the results were consolidated and shared among the network members. Demonstration trials in farmers' fields were conducted, field days were organized, and lead farmers were selected to produce good quality seed. Improved seed production was undertaken by various regional, national, and private agencies as the demand for seed was good and the price was attractive.

International mungbean nurseries were the first conduits by which the improved breeding lines were distributed to national partners, who evaluated the lines and reported data back to AVRDC. Through this close cooperation, the national partners were able to release improved varieties to their farmers. Because the improved varieties were so well adapted to local conditions and offered net benefits and advantages, the farmers readily adopted them soon after they were released (Evenson and Gollin 2003). However, there were differences in adoption rates between countries, and regions within a country. As of January 2009, national partners in 27 countries have released 112 improved mungbean varieties to their farmers.

With technical support from AVRDC, the national agricultural research systems in each country gradually assumed greater responsibility for breeding and crop management research. Today they continue to extend the improved technology while adapting and improving it, assuring the sustainability and continued success of the intervention.

The improved mungbean technologies gained acceptance in each country through the excellent collaboration of government policymakers and researchers who carefully planned and conducted scientific research trials in strategic locations, a systematic and organized seed production and distribution system, and the sincere interest and enthusiasm of extension workers, NGOs, and farmers.

Impact of Improved Mungbean in Asia

The transformation of mungbean from a marginal to a major crop has brought many benefits to Asia (Table 2). The major beneficiaries of the intervention are the poor, especially children and women, whose diets lacked much-needed protein and iron. Both urban and rural consumers now have access to improved quality mungbean available at reasonable cost. The crop offers the potential for a new income stream for small-scale farmers.

Table 2. Summary of the impact of improved mungbean in Asia (1984-2006)

Areas of impact	Estimated impact
Adoption of improved varieties	
• Percent of total mungbean area	50 to 95%
• Area covered	2,932,000 ha
• Number of farmers	1,466,000[a]
• Average growth rate of area	-0.1 to 22%
Increase in production	35% (800,000 t)[b]
Average annual growth rate for production	-0.3 to 23.5%
Yield increase	28 to 55% (187 to 426 kg/ha)
Average annual growth rate for yield	-0.1 to 1.7%
Increase in income due to	
• Increase in yield	28 to 55%
• Increase in paddy yield with rice-wheat-mungbean rotation	$148,700,000[c]
Economic benefit due to improved health of anemic women, enhancing productivity	$3,500,000 to 4,000,000/country[d]
Increase in consumption of mungbean	22 to 66%
Anemic children benefited	1,500,000[e]

[a] Assuming an average land holding of 2 ha per farmer across different countries.
[b] Production in Asia increased from 2.3 million tons in 1985 to 3.1 million tons in 2000.
[c] Rice-wheat-mungbean rotations gave 450 kg/ha higher paddy yield than rice-wheat-fallow rotation. It is assumed that the whole 2.932 million ha were in rotation.
[d] It is assumed that the average is the same as that observed in Pakistan.
[e] Assuming that an average farm family has two children across the countries.

Today, improved mungbean constitutes more than 25 percent of world mungbean production (Shanmugasundaram 2001). Improved mungbean varieties occupy almost 90 percent of the mungbean area in Pakistan and Thailand (Jansen and Charnnarongkul 1992; Ali et al. 1997), 85 percent in China (Huijie et al. 2003), around 50 percent in Bangladesh, and 50 percent in Myanmar (Weinberger 2003a). In Punjab in India the improved variety SML668 was planted on 95 percent (summer) and 60 percent (rainy season) of the mungbean area in 2006. Nepal and Sri Lanka have released two improved varieties each; however, the extent of their adoption is unavailable. In South Asia the area under pulses in general (including mungbean) decreased from 27 to 24 million ha from 1963 to 2003, although the production increased from 13.5 to 15 million tons during the same period (Jat et al. 2006).

Due to the introduction of improved mungbean, production in Asia increased 35 percent, from 2.3 million tons in 1985 to 3.1 million tons in 2000 (Weinberger 2003a). Area under mungbean before and after the intervention is shown in Table 3.

Table 3. Estimated area (ha) under mungbean before and after the intervention in different Asian countries

Country	Before intervention	After intervention
Bangladesh	15,000 (1985)	70,000 (2006)
China	547,000 (1984)	776,000 (2000)
India	284,500 (1980)	550,000 (2008)
Myanmar	43,000 (1980-81)	1,000,000 (1998-99)
Pakistan	100,000 (1985)	200,000 (2000)
Sri Lanka	14,000 (1980)	33,200 (1995)
Thailand	308,000 (1984)	335,000 (1995)

Source: Bangladesh, China, Pakistan, and Sri Lanka—Weinberger (2003a); India—Shanmugasundaram (2006); Myanmar—Bahl (1999); Thailand—Chainuvati et al. (1988) and Srinives (1998).

The producer and consumer surplus generated by improved mungbean and production technologies in Pakistan has been estimated to be around US$20 million per year. [1] The benefit–cost ratio ranged from 1.87 to 2.21, depending upon the variety, in Pakistan (Ali et al. 1997). In China, annual surpluses were estimated at $56.4 million (on 10 percent cost reduction scenario) to $129.9 million (on 25 percent cost reduction scenario), with an average of $98 million and an internal rate of return of 108 percent (Huijie et al. 2003; Weinberger 2003a). The benefit–cost ratio for farmers using the improved varieties has been estimated to be around 2.18 in Bangladesh (Afzal et al. 2006). The average return on variable cost (from a two-year study) was 119 percent and 144 percent for mungbean after wheat, and after potato, respectively, in Punjab, India (Grover et al. 2006). The benefit–cost ratio of improved mungbean technology in Rajasthan, India was 2.0 compared to 1.44 for farmers' technology between 1991 and 2000 (Siag and Prakash 2006). It would be useful to have economic benefit assessment studies conducted for Nepal, Bhutan, and Sri Lanka.

The rice-wheat cropping system is practiced on 26 million ha in South and East Asia (Abrol et al. 1997; Timsina and Connor 2007). Including mungbean in the rice-wheat rotation system has diversified and strengthened the cropping system, alleviated the disadvantages of the cereal–cereal cropping system, and improved the productivity of the soil. Mungbean enriches the soil and breaks the soil fatigue caused by cereal–cereal rotations. Including mungbean in a rice rotation has increased the yield of paddy and the income of farmers in Punjab (Weinberger 2003a).

As for its health benefits, mungbean is rich in protein (24 percent) and iron. The improved mungbean varieties contain 6 mg of iron per 100 g raw seed (Vijayalakshmi et al. 2003) whereas traditional mungbean varieties have only 3.0 to 3.5 mg (Gopalan et al. 1989). Weinberger (2003b) studied the impact of enhanced iron consumption through mungbean and its effect on the productivity of anemic female workers in Pakistan. The study showed the economic benefit to the country was $3.51 to 4.21 million in additional annual income primarily from women whose health improved from mungbean consumption. A feeding trial was conducted in Coimbatore, India, to determine the contribution of mungbean in alleviating anemia in children. The results showed the health benefits, including improvement in physical and mental abilities of children, from improving the yield and production of mungbean (Vijayalakshmi et al. 2003).

[1] All dollars are U.S. dollars.

2. THE INTERVENTION: IMPROVING AND DISSEMINATING THE MUNGBEAN

Inception

The Green Revolution was a boon to Asia, bringing much-needed food energy from cereals to the region (ESCAP 1985). The per capita yield of wheat increased substantially from 1961 to 1972, but in the same period, per capita yield of legumes decreased in South Asia. Pakistan, for example, spent valuable foreign exchange to import legumes to meet domestic demand (Ali et al. 1997).

Legumes, also referred to as pulses, are the major source of protein in Asia and constitute an important supplement to the predominantly cereal-based diet (Singh 1988; Paroda 1995). Cereals are deficient in the amino acid lysine, which legumes can provide; legumes are low in sulfur-rich amino acids, which cereals can provide (Thirumaran and Seralathan 1988).

Recognizing the importance of a balanced diet for the poor in Asia, in the early 1960s, Frank Parker, USAID Assistant Director for Research and Technology, Rural and Community Development Service, Office of Technical Cooperation and Research, conceived the idea of establishing a vegetable center in Asia (Fletcher 1993). The Asian Vegetable Research and Development Center (AVRDC) opened in Taiwan in 1971 to enhance the diets, cropping systems, and incomes of poor farmers in Asia through the production and consumption of vegetables. Mungbean was one of two legumes (the other was vegetable soybean) the new center selected for crop improvement.

Background on Mungbean

The major legumes in Asia are chickpea, (*Cicer arietinum* L), pigeonpea (*Cajanus cajan* L.), and mungbean (*Vigna radiata* var. *radiata* L. Wilczek). Legume seed is high in protein, micronutrients, vitamins, minerals, and fiber; legume plants are able to fix atmospheric nitrogen in the soil through their symbiotic association with the *Rhizobium* bacteria, and are adaptable to a number of cropping systems (Shanmugasundaram 2003). The International Crop Research Institute for the Tropics (ICRISAT) in India carried out research and development on chickpea and pigeonpea. AVRDC scientists and administration felt the center could make a significant contribution by developing mungbean to improve the quality of diets in Asia. Mungbean is a warm season crop (AVRDC 1981) that can grow during hot, wet seasons and be cultivated in the arid and semi-arid tropics (Pannu and Singh 1988; Pandey et al. 1988).

Traditional indeterminate mungbean varieties had long growth duration (90 to 110 days) and required multiple harvests (suitable for home gardening, but unsuitable for commercial production due to high labor costs). The traditional varieties were susceptible to key diseases such as Cercospora leaf spot, powdery mildew, and *Mungbean yellow mosaic virus* (MYMV); insect pests such as beanfly (*Melanagromyza sojae*, *M. dolichostigma,* and *Ophiomyia centrosematis*), lima bean pod borer (*Etiella zinckenella*), and mungbean weevil (*Callosobruchus chinensis*); and did not respond to inputs (AVRDC 1975, 1977). In a semi-wild state, mungbean was of little value; AVRDC saw an opportunity to domesticate the crop and make substantial improvements. To achieve this objective, it was essential to have a broad, deep pool of genetic diversity for breeders to use. AVRDC obtained mungbean germplasm from various laboratories and sources; today the center's mungbean collection contains 10,733 accessions of *Vigna* and related species (Table 4).

Table 4. Number of *Vigna* accessions in AVRDC's genebank, April 21, 2009

Genus	Species	Subtaxa	No. of accessions
Vigna	*aconitifolia*		22
Vigna	*angularis*		2,396
Vigna	*caracalla*		1
Vigna	*glabrescens*		3
Vigna	*luteola*		2
Vigna	*marina*		3
Vigna	*mungo*		512
	mungo	var. *silvestris*	250
Vigna	*parkeri*		1
Vigna	*radiata*	var. *radiata*	5,900
	radiata	var. *sublobata*	5
Vigna	*spp.*		193
Vigna	*trilobata*		2
Vigna	*umbellata*		290
Vigna	*unguiculata*		360
	unguiculata	subsp. *sesquipedalis*	479
	unguiculata	subsp. *unguiculata*	313
Vigna	*vexillata*		1
Total			10,733

Source: Dr. Andreas Ebert, AVRDC – The World Vegetable Center, Genetic Resources and Seed Unit, personal communication.

Vision of the Ideal Mungbean for Asia

The initial vision at AVRDC for the mungbean improvement program came from the plant breeders, plant physiologists, plant pathologists, entomologists, biochemists, and economists. Plant breeder David R. MacKenzie and plant physiologist Henry Wu had a healthy and constructive debate on the type of mungbean plant breeders should develop. Finally they agreed on a short, determinate plant type with all the pods on the top of the plant (MacKenzie and Shanmugasundaram 1973). In addition, it was agreed that breeders would aim for a plant with the following characteristics (Fernandez and Shanmugasundaram 1988; Shanmugasundaram and Kim 1996). It should

- have a stable potential yield of > 2 tons/ha;
- have a maturity duration of around 60 to 75 days;
- have uniform maturity so that the harvest could be completed in one attempt;
- have bold seed size (50 to 60 g for 1,000 seeds instead of the 25 to 30 g for 1,000 seeds produced by the local varieties);
- be resistant to Cercospora leaf spot, powdery mildew, bean fly, pod borer, and bruchid weevil;
- be more compact;
- have a higher harvest index;

- be less sensitive to photoperiod; and
- be more determinate in growth habit compared to traditional varieties.

Collaboration to Breed Mungbean Varieties

Having agreed on a blueprint for the mungbean plant type, the breeders began screening germplasm for the required traits. Promising lines and superior germplasm accessions were evaluated annually for adaptation and suitability in many countries in different locations and seasons through the International Mungbean Nursery (IMN). The University of Missouri conducted the first four IMNs supported by USAID from 1971 to 1975 (Morton et al. 1982). AVRDC carried out the IMN from 1976 onwards. Through the mechanism of the IMN, improved mungbean lines were spread initially to Southeast Asia, South Asia, East Asia, and China, and then to other parts of the globe (Fernandez and Shanmugasundaram 1988). This intensive, extensive, formal, and informal collaboration has led to the release of 112 improved mungbean varieties based on AVRDC breeding lines and germplasm in 27 countries worldwide, of which 53 were from nine countries discussed in this review (Appendix A). The improved varieties have replaced from 50–100 percent of local varieties. (Ali et al. 1997; Shanmugasundaram 2001; Huijie et al. 2003; Weinberger 2003a)

Development of an Improved Mungbean

Mungbean breeders Ricardo Lantican and Rudy Navarro at the Institute of Plant Breeding, University of the Philippines developed an early maturing, compact plant type with uniform maturity and bold seeds. The most prominent lines were CES 55, CES 87, MG 50-10A, and MD 15-2. However, the Philippine genotypes were susceptible to major diseases such as Cercospora leaf spot and powdery mildew (Lantican and Navarro 1988).

Varieties bred at the Indian Agricultural Research Institute (IARI), the All India Coordinated Pulses Program at Kanpur, and other regional research centers did carry resistance to Cercospora leaf spot and powdery mildew and were able to withstand adverse soil and climate conditions with minimum or no inputs. However, the Indian varieties were found to be indeterminate, late maturing, and small-seeded (Lantican and Navarro 1988; Tickoo et al. 1988).

In the mid-1970s, the Institute of Plant Breeding at the University of the Philippines developed improved mungbean with high yield and disease resistance for the Philippines, termed the “Pag-asa” series: Pag-asa 1, 2, and 3 (IPB 1976–78). AVRDC’s Philippines Outreach Program and Elena Catipon, Benjamin Legaspi, Flora A. Jarilla, and all their team members from the Bureau of Plant Industry, Philippines developed a series of varieties for the Philippines based on AVRDC improved lines, which were used in the International Rice Research Institute (IRRI) cropping system network for testing in Southeast Asia (Catipon et al. 1988).

AVRDC decided to combine the desirable traits of the varieties from the Philippines and India. Data collected for 31 advanced superior breeding lines and promising germplasm accessions from International Mungbean Nurseries No. 5–12 were evaluated for environmental sensitivity. In total 21 lines were selected and placed into three groups representing diverse environments (Table 5).

Table 5. Mungbean lines suitable for diverse environments based on environmental sensitivity

Group	Lines
Group A: High yielding, but suitable for favorable environments only	VC 1560D, VC 2565A, VC 2719A, VC 2755A, VC 2764A, VC2768A, VC 2778A
Group B: High yielding and stable in unfavorable environments	VC 1168B, VC 1209B, VC 1562A, VC1628A, VC 1973A, VC 1974A, VC 2523A, VC 2582A
Group C: Suitable for low-yielding environments	VC 1089A, VC 1163A, VC 1168A, V 1381, V 1944

Source: Fernandez and Shanmugasundaram 1988

In an analysis of various breeding lines for photoperiodic response, the following mungbean lines were found to be relatively less sensitive to photoperiod and they also had high yield and wide adaptation to diverse environments: VC 1973A, VC 1628A, and VC 1158B (AVRDC 1988). Fernandez and Shanmugasundaram (1988) noted that short-duration mungbean with less sensitivity to photoperiod and temperature would be a promising candidate for crop diversification. In the semi-arid and arid tropics, drought is one of the factors affecting the stability of yield in mungbean. VC 1163D, VC 2750A, VC 2754A, and VC 2768A were found to be tolerant to drought (AVRDC 1988).

The potential yield loss due to Cercospora leaf spot and powdery mildew was reported to be 40 percent and 58 percent respectively (Shanmugasundaram and Tschanz 1987). A number of elite lines with high yield, synchronous maturity, and resistance to leaf spot and mildew were developed. By 1987, 16 countries had released 28 varieties to their farmers (Fernandez and Shanmugasundaram 1988).

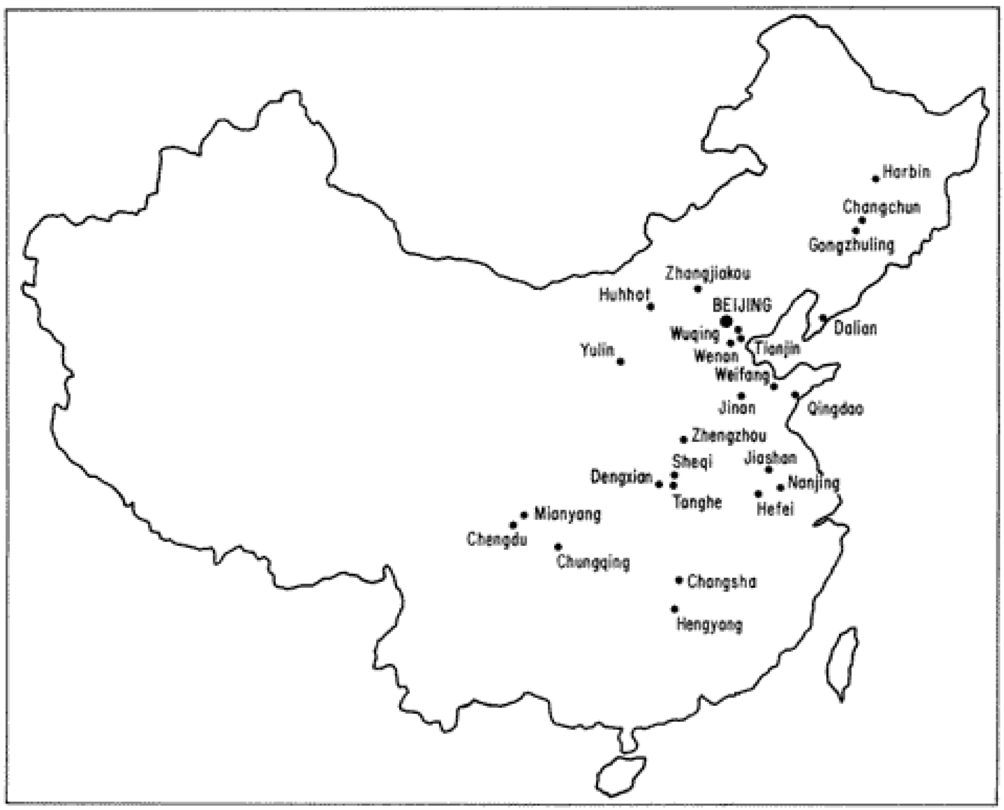
Development in Thailand

In Thailand, several agricultural and vocational colleges located throughout the country along with the Department of Agriculture, the Department of Agricultural Extension, regional research stations, and other international agricultural research institutes cooperated with AVRDC to improve mungbean. Arwooth Na Lampang of the Department of Agriculture, Peerasak Srinives of Kasetsart University, Charles Y. Yang of the Thailand Outreach Program, and Chavalvut Chainuvati of the Department of Agricultural Extension and their team members were at the forefront of the Thai effort. The Department of Agriculture had been evaluating AVRDC mungbean since 1974; its active mungbean program evaluated IMN lines from the University of Missouri and received improved lines from AVRDC, the Philippines, and the International Rice Research Institute. In 1982, the results from the 10th IMN, from trials at 218 locations in 14 countries, revealed that VC 2778A and VC 1973A had consistently higher yields at 1,189 and 1,145 kg/ha respectively, and produced the bolder seed preferred by the market (Ahn et al. 1985). From 1982 to 1984 a consolidated testing network involving all the partners mentioned above conducted 28 trials in various experiment stations around Thailand. The results showed the distinct superiority and performance of VC 1973A and VC 2778A, which out-yielded the local check Uthong 1 by as much as 37 percent. Data obtained from farmers' fields showed the two VC lines had 20 percent higher yield than Uthong 1. Kasetsart University successfully released VC 1973A as Kamphaengsaen 1 (KPS 1) and VC 2778A as Kamphaengsaen 2 (KPS 2) (Fernandez and Shanmugasundaram 1988). The Department of Agriculture released Chai Nat 60 in honor of the 60th birthday of Thailand's King, and later another variety, Chai Nat 36. Prince of Songkla University released PSU 1. These varieties now occupy almost 100 percent of the mungbean grown in Thailand. Pedigrees are listed in the Appendix, Table A1.

Development in China

Mungbean is an ancient crop cultivated across a large area in China. Mungbean germplasm has been collected from a wide geographical area ranging from lat 21–43° N to long 74–121° E (Lin and Cheng 1988). The Institute of Crop Germplasm Resources (ICGR) at the Chinese Academy of Agricultural Sciences (CAAS), established in 1978, has collected more than 3m000 accessions from various provinces in China. Beginning in 1983, improved mungbean lines from the 11th IMN onwards and germplasm from AVRDC were sent regularly to China for evaluation through AVRDC's Thailand Outreach Program (now the Asian Regional Center). Trial plantings of mungbean lines were undertaken throughout China (Figure 1).

Figure 1. Mungbean trials throughout China (1983-1988)



Source: Lin and Cheng 1988

With its erect and compact plant type, resistance to lodging, pods set on the upper nodes, earliness and uniform maturity, high and stable yield, and bold seeds when planted under conditions of medium- to above-average fertility and moisture, VC 1973A created excitement among researchers and demand from farmers in China. Recognizing the opportunity, the CAAS supported the seed multiplication of VC 1973A. Beginning with 3.5 kg of seed in 1984, through careful planting in spring, summer, and autumn seasons, CAAS increased the seed quantity to plant 20,000 ha in 1987 (Appendix Table A2).

Based on the regression analysis of 20 mungbean varieties at 11 trial sites in China it was concluded that VC 1973A was a stable and widely adapted variety with an average yield of 1531 kg/ha. The potential yield of VC 1973A was reported to be around 4,500 kg/ha (Cheng and Lin 1993). VC 1973A was released as Zhong Lu #1; it was the first mungbean variety released for nationwide cultivation in China since 1949. In 1989, the total area planted to Zhong Lu #1 reached 267,000 ha

(Cheng 1993; Cheng et al. 1993; Shanmugasundaram 2003). Zhong Lu #1 has been released in many provinces throughout China under a number of different names. Breeding lines VC 2778A and VC 2768A performed well under favorable environments with better inputs. They were released as E Lu #2 and Su Lu #1 respectively. VC 1628A (Yueh Yi #3) and VC 2917A (Zhong Lu #2) were also released to farmers (Huanyu and Zhizong 1993).

Through the financial support from the International Development Center of Canada, researchers from various parts of China came to AVRDC's Thailand Outreach Program to learn how to evaluate mungbean varieties and produce good quality seed. More than 100 scientists from China received the training; these scientists were able to extend mungbean successfully across China. AVRDC also organized an international mungbean symposium in Bangkok, Thailand in 1988 in which scientists from China actively participated and benefited. In collaboration with CAAS, AVRDC organized an in-country meeting on mungbean in which the scientists reported on the progress of mungbean research and extension of the varieties in China. Li-fen Lin and Xu-Zhen Cheng from the Institute of Crop Germplasm Resources, CAAS, Beijing, researchers and extension staff of regional academies of agricultural sciences all over China, and private institutions were responsible for the success of mungbean improvement in China. The untiring effort and dedication of Charles Y. Yang, then-Director of AVRDC's Thailand Outreach Program made the collaboration with China a reality. Later, R. T. Opena, Director of the Asian Regional Center, strengthened the partnership. AVRDC breeders Hyo-Guen Park, Chang Soo Ahn, D. H. Kim, George C. J. Fernandez, and S. Shanmugasundaram were responsible for developing and facilitating the movement of germplasm and breeding lines for China.

Development in Myanmar

Following the identification of VC 1973A as promising breeding line, in 1982 R.K. Palis, the International Rice Research Institute resident scientist in Myanmar, expressed interest in evaluating mungbean. Through its Thailand Outreach Program, AVRDC provided the seeds of selected mungbean lines and Dr. Palis hand-carried the seeds to Myanmar, where he conducted trials. However, AVRDC did not hear from Myanmar for quite some time; Dr. Palis had left the country. Then, in the early 1990s, the FAO representative in Myanmar contacted AVRDC, noting lines VC 1973A and VC 2768A were doing well, and asking if it would be possible for the Center to supply large quantities of the seed for extension to farmers. AVRDC does not produce quantities of seed at the levels required for large-scale distribution; however, the Center agreed to provide 100 kg of seed of the two lines to FAO for multiplication. From then onwards, FAO, AVRDC's Asian Regional Center, and the Myanmar Government have actively produced seed of VC 1973A and VC 2768A and several other breeding lines, which have been enthusiastically accepted by farmers. The Asian Regional Center provided training for Myanmar scientists in varietal evaluation and seed production, which helped to expand the area and production of mungbean.

Development in South Asia

Although the success of improved mungbean in Southeast Asia and China was spectacular (Shanmugasundaram 2001), South Asia was the major mungbean production area in need of improved varieties. In South Asia, *Mungbean yellow mosaic virus* (MYMV) severely constrained mungbean expansion and production. The disease was not present in Southeast Asia and Taiwan, where the Center has its headquarters, so AVRDC waited for an opportune time to conduct collaborative research with South Asia to address the problem. During the mid-1980s, the Nuclear Institute for Agriculture and Biology (NIAB) in Pakistan identified a stable and high level of resistance to MYMV through irradiation of local variety 6601 (Ali et al. 1997). In 1991, AVRDC organized a MYMV workshop and published the proceedings (Green and Kim 1992). Workshop participants recommended the establishment of a regional collaborative network to address and solve the problem of MYMV in the region. AVRDC was asked to coordinate the network. In 1992, AVRDC established an informal network with Pakistan to develop MYMV-resistant, high-yielding mungbean varieties for South Asia. Shuttle breeding between AVRDC and NIAB enabled the development of improved MYMV-resistant varieties for South Asia.

Pakistan served as the gateway for AVRDC to initiate breeding for MYMV resistance in South Asia. The Nuclear Institute for Agriculture and Biology (NIAB) in Faisalabad identified MYMV resistance through irradiation of the local variety. An initial informal network between AVRDC, NIAB, the National Agricultural Research Center (NARC, Pakistan) in Islamabad, and other national and provincial organizations conducted mungbean research in Pakistan in 1992 (Ali et al. 1997). During this period D. H. Kim, the mungbean breeder from AVRDC headquarters, moved to the Asian Regional Center in Bangkok. In 1981, a reciprocal cross was made between MYMV-susceptible VC 1973A and a MYMV resistant local variety, 6601. Hybrid seeds were treated with 10 k-rad gamma rays. The Pakistan mungbean breeders conducted detailed inheritance studies on MYMV resistance and seed size, and evaluated the F_2 to F_{12} generations from 1981 to 1986. Six promising lines were selected (Malik et al. 1988).

MYMV was not present in Taiwan, the Center's headquarters, but AVRDC breeders needed to evaluate the performance of mungbean varieties exposed to the virus. Shuttle breeding between AVRDC and Pakistan, intensified through the Asian Regional Center, was the answer. Hybridizations between MYMV resistant Pakistan lines and improved MYMV susceptible AVRDC lines were made. The resulting generations were screened at AVRDC for high yield, earliness, synchronous maturity, bold seeds, Cercospora leaf spot and powdery mildew resistance, then returned to Pakistan for selection for MYMV resistance. Resistant materials were again selected for desirable traits at AVRDC and sent back to Pakistan for further selection. Through shuttle breeding, a number of promising MYMV-resistant lines were selected, including NM92 and NM94.

Shuttle breeding was also helpful in developing widely adapted varieties. Combining NM92 with AVRDC improved lines produced a number of new selections. NM92 was officially released for farmers in 1993 in Pakistan; however, seed of the variety already had been shipped to farmers in 1992. By 1994 nearly 51 percent of the sampled farmers were growing NM92, replacing the local variety. Most farmers broadcast-sowed the local variety, but nearly 20 percent of the farmers used drilling to plant improved variety NM92 in rows. This suggests the improved variety served as a catalyst, prompting farmers to adopt improved cultural practices because yield and profit from improved varieties are higher and risk is lower (Ali et al. 1997). In Pakistan, Ilyas Ahmad Malik, Muhammad Bashir, Muhammad Zubair, and Bashir Ahmad, their colleagues at the NIAB, NARC, Ayub Agricultural Research Institute (AARI), and other regional agricultural research institutions were responsible for the successful production and extension of NM92 and eight other MYMV-resistant varieties. Improved varieties now occupy nearly 50 percent of the total mungbean area in Pakistan (Shanmugasundaram 1988; Ali et al. 1997). The improved varieties have a yield potential of up to 1800 kg/ha, compared with the local variety's 1000 kg/ha; they mature in about 60 days compared to 90 days for the local variety; they mature uniformly, so that they can be harvested in one picking. Farmers readily recognized the advantage and benefit from the improved variety.

Extending Mungbean Across South Asia Through SAVERNET

To extend the benefits of the new improved mungbean to all countries in South Asia (the world's major producer of mungbean, and where MYMV is the major factor limiting production), an umbrella agreement was needed to promote collaboration. AVRDC had earlier established a South Asia Vegetable Research Network (SAVERNET), and all South Asian countries were signatories of the network. SAVERNET committee members agreed to allow a mungbean subnetwork to be organized under the umbrella of SAVERNET. As the executive agency, AVRDC, in consultation with representatives of South Asian countries, prepared a project proposal "Promotion of Mungbean Research Outputs for Farmer Adoption in South Asia" and submitted it to the Department for International Development (DFID), United Kingdom. DFID approved a three-year Holdback project R6719 (H) in March 1997. The project was later extended for another year without additional funding.

The mungbean subnetwork organized an international workshop on mungbean in September 1997 in New Delhi, India to explore new MYMV technologies, share improved cultural practices, and craft a master work plan. In total, 45 participants from six South Asian countries (Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka), Australia, and Thailand attended.

The participants agreed to conduct trials in two seasons (rainy and summer) using 17 entries for the rainy season and 16 entries for summer. Seed of all the agreed varieties were multiplied at AVRDC headquarters in Taiwan and each trial set was packaged and sent to the participating network partners (Appendix Tables A3 and A4). The actual entries evaluated are listed in the Appendix, Tables A5 and A6. The trials were conducted in the rainy and summer seasons in 14 and 18 locations, respectively (Appendix Tables A7 and A8).

In total, 64 multilocation trials were conducted in six countries in three years. Among them, 31 trials were during the summer season, 15 trials were conducted during the rainy season, and 18 trials were conducted in the dry season (Appendix Table A9). Sixteen scientists from six countries were trained in a short course on multilocation testing of mungbean lines (Appendix Table A10).

Institutions from six countries who participated in evaluating the shared genotypes are listed in Appendix Table A11. The workshop laid a solid foundation for successful mungbean improvement and expansion in South Asia. Due to the logistics involved in quarantine procedures, some network partners experienced delays in conducting the trials. To allow all partners to participate, the project was extended for an additional year.

Statistical analysis of the multilocation trials indicated a highly significant genotype x environment interaction. Therefore, an additive main effect and multiplicative interaction effect (AMMI) analysis and pattern analysis were conducted to identify the components of interaction effects and select the varieties best suited to specific locations. The results showed that days to flower, days to maturity, and 1,000 seed weight were the principal component 1, while the MYMV rating was the principal component 2 that caused the interaction, depending on the temperature and photoperiod of the various locations and seasons. Varieties PDM54 from the Indian Institute for Pulses Research and NM92 from Pakistan/AVRDC were the most outstanding varieties. The former was a late-maturing variety; the latter was an early-maturing one. Farmers preferred the early maturing variety to fit into the cropping system for the summer season. NM94 was also early with resistance to MYMV and selected by farmers, although it did not rank as high as NM92 or PDM54.

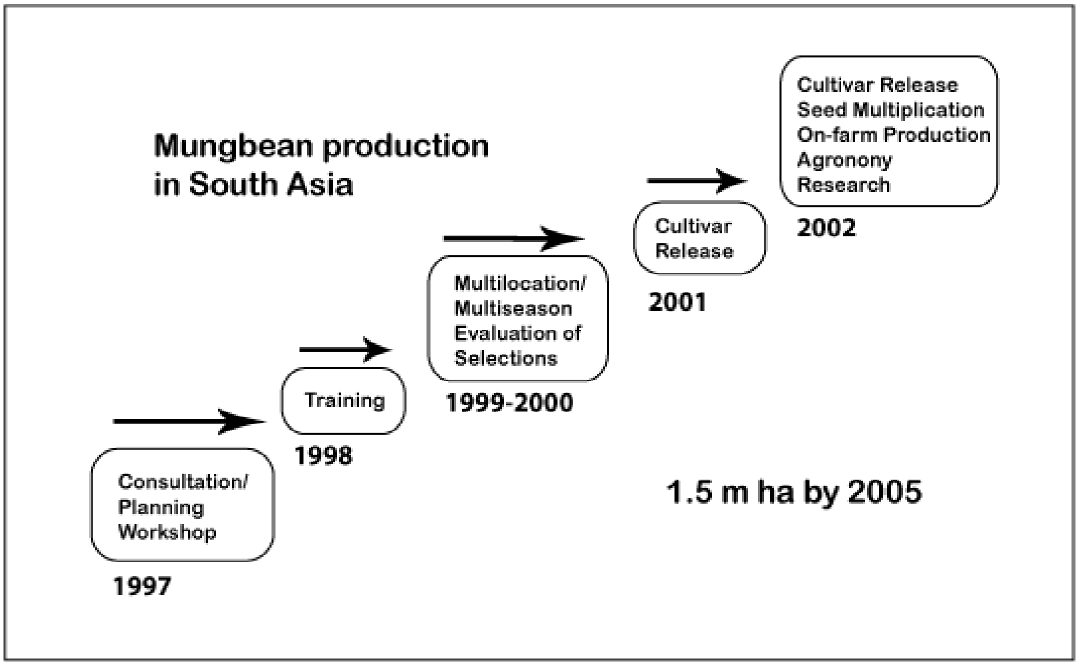
Varieties ML 267, ML 613, NM92, and VC6372 (45-8-1) were found to be consistently resistant to MYMV across many locations. Similarly, NM94 and VC6368 (46-40-4) also had high levels of resistance to MYMV. Multilocation trials also showed that MYMV is more severe in the rainy season than in the summer season. Based on the combined data collected from all the locations it was found that hot spots for screening MYMV in the summer season were Pantnagar (India), Gazipur and Mymensingh (Bangladesh), and Islamabad in Pakistan. Bhutan and Sri Lanka did not have a problem with MYMV.

Within the short span of four years, through multilocation trials and evaluation in farmers' fields, new improved varieties from the mungbean subnetwork were released in Bangladesh and India (see Appendix Table A1). Accomplishments of the program also include the rapid multiplication of the newly released varieties and promising lines for farmer adoption (Appendix Table A12). From the results of the trials, Bangladesh, Pakistan, and India identified varieties are resistant/tolerant to MYMV with a yield of about 2 tons/ha that mature 55 to 65 days after sowing. Bhutan and Sri Lanka identified varieties with more than 2 tons/ha.

Extending Improved Mungbean Across Asia

DFID recognized the potential of the short-maturity (55 to 65 days), MYMV-resistant, synchronously maturing, bold-seeded, high-yielding mungbean varieties for diversifying the rice-wheat cropping system for millions of small farmers in South Asia. In March 2002, DFID approved a two-year project to improve rural household income and employment opportunities, diversify diets, and increase nutritional security through the increased availability of pulses (mungbean) for the poor, and to enhance soil fertility in the region through the participation of 500,000 farmers. The project's purpose was to help farmers diversify rice-wheat rotations by adopting improved mungbean cultivars; persuade national agricultural research systems (NARS) to use improved mungbean germplasm and methodologies for location-specific adaptation; and promote mungbean consumption for balanced diets. Figure 2 traces the take-off pathway of mungbean in South Asia.

Figure 2. Initial take-off pathway of mungbean in South Asia, 1997–2005



Source: S. Shanmugasundaram.

In total, 40 agronomic experiments were conducted at Punjab Agricultural University, India; at Jessore, Dinajpur, and Gazipur in Bangladesh; and at AVRDC in 2002 and 2003. Based on the results, agronomic practices guides were prepared in local languages and distributed to farmers in each country.

Due to drought, farmers in Punjab were forced to plough under their transplanted rice seedlings in the 2003 rainy season. The government provided improved mungbean SML668 for 2,000 farmers for the rainy season. The crop grew well and the farmers obtained a yield of about 1.0 to 1.5 tons/ha. SML668 was approved and released for rainy season planting. The economic performance of improved mungbean, demonstrated through farmers' management practices, is shown in Appendix Table A13.

Punjab Agricultural University in Ludhiana produced 15 tons of SML668 seed during the summer and rainy seasons in 2001. In 2002, eight different agencies in the summer and five different agencies in the rainy season produced 344 and 465 tons of SML668 seed respectively (Appendix Tables A14 and A15).

Due to the continuing demand for the new improved variety SML668, a Seed Village Program was initiated in summer 2003 with technical input and advice from scientists at Punjab Agricultural University and officers of the Department of Agriculture, Punjab. Each farmer in the seed village program was given, at no cost, seed sufficient to plant 0.4 ha. Six regions were chosen for the Seed Village Program in Punjab. In each region, three to four villages were selected to form a cluster. Forty-five farmers were selected for each cluster. In total 270 farmers participated. From 0.4 ha, each farmer produced approximately 0.4 tons/ha of seed. The seed was planted again in the rainy season of 2003. At the end of the season, approximately 2,700 tons of seed was produced through the Seed Village Program alone (Table 6). In the following year, farmers used their own seed for seed multiplication, enhancing the sustainability of the program. The university and the Department of Agriculture monitored the purity and quality of the seed produced. The Seed Village Program offered two major advantages: seed quality was ensured; and seed was disseminated from farmer to farmer very rapidly.

Table 6. Seed production through Seed Village Programs, 2003

Production parameter	
No. of villages in each Seed Village Program	6
No. of farmers in each Seed Village Program	45
Each farmer given seed for planting	0.4 ha
Seed production from 0.4 ha	0.4 t
Area planted with 0.4 tons in *Kharif* 2003	10 ha
Seed produced by each farmer in *Kharif* 2003	10 t
Total seed production in one Seed Village Program (10 x 45)	450 t

Source: Bains et al. 2006.

In 2003 summer and rainy seasons, approximately 6,500 tons of seed was produced (Appendix Tables A16 and A17), sufficient for planting nearly 200,000 ha. In 2004, Punjab Agricultural University farms alone planted 40.8 ha for seed production in the summer (Appendix Table A18). Punjab State Seed Corporation (PUNSEED) produced 100 tons during the summer. At a 2002 Farmers' Fair (*Kishan Mela*), Punjab Agricultural University sold 7,000 kg of SML668 seed to 3,500 farmers. Due to the intensive effort, the area under mungbean increased during the rainy season from 23,000 ha in 2001 to 65,000 ha in 2003. In summer 2003, the area planted to mungbean was estimated at 25,000 ha, and increased to 40,000 ha in 2004 (Appendix Table A19).

Farmers from neighboring states including Rajasthan, Haryana, western Uttar Pradesh, and Bihar came to Punjab to obtain the seeds of improved varieties, especially during *Kishan Mela* at Punjab Agricultural University. In 2003, 50 tons of SML668 seed were sold to Rajasthan. Punjab Agricultural University also provided 500 kg of SML668 seed to Nepal and approximately 500 kg to the Rice-Wheat Consortium (RWC) of CIMMYT for use by RWC farmers. To maintain pure seed of SML668, breeders at Punjab Agricultural University selected single plant progenies (true to type) to multiply (Appendix Table A20). The farmers received a price of Rs 13 to 26/kg for SML668. Some rainy season farmers received only Rs 7.6/kg due to very poor quality of seed caused by rain damage. The cost of SML668 seed from Punjab Agricultural University was Rs 36/kg. To plant 1 hectare, a farmer spent about Rs 1,450. His net return from mungbean was estimated at Rs 14,652/ha in 60 days. Some farmers sold the seed at Rs 60/kg. In India, the Indian Agricultural Research Institute and Punjab Agricultural University, along with six other agencies and the Punjab State Seed Corporation, produced approximately 90 tons of seeds of Pusa Vishal, which was sufficient to cover about 2,250 ha in 2004 (Sekhon et al. 2006).

In Bangladesh, seven agencies multiplied the seed of six mungbean varieties for extension to farmers. A seed exchange program was instituted in which the farmers were given seed of improved cultivars in exchange for seed of their local variety. The total quantity of seeds produced was 11,538 tons (Appendix Table A21). The seed was sufficient to plant about 330,000 ha in 2004.

The Nepal Agricultural Research Institute, CIMMYT, Local Initiatives for Biodiversity Research and Development, and the Forum for Rural Welfare and Agricultural Reform for Development conducted full-scale on-farm participatory trials in 21 districts in 2003. The improved varieties were well adapted to the spring, summer, and autumn seasons in the low hill and *terai* agroecosystems of Nepal, and the Indo-Gangetic Plains (Khanal et al. 2004). Improved varieties occupy about 12,000 ha in Nepal (Shanmugasundaram 2006).

Eight scientists from India and two from Bangladesh were trained for three months at AVRDC in 2002 and 2003. Two Bangladeshi scientists visited Punjab Agricultural University and observed the research, extension, and mechanical harvesting of mungbean and participated in Kishan Mela in 2003. Six scientists from Punjab Agricultural University, including Vice Chancellor K. S. Aulakh and Director of Research G. S. Nanda, participated in a monitoring tour of Bangladesh and observed the impressive progress of improved mungbean in 2002. After observing the Seed Village Program in Punjab, the Bangladesh scientists introduced it in Bangladesh. Bangladesh then sent about 300 kg of BARIMUNG 5 seed to Nepal in 2006.

3. IMPACT OF IMPROVED MUNGBEAN IN SOUTH ASIA

Assessments of the impact of improved mungbean have been conducted successfully in most countries highlighted in this paper. The number of improved varieties released was the easiest output to assess; it reflects the use of germplasm combined with serendipitous selection, insight, imagination and sheer hard work (Anderson 1997). Mungbean has strengthened economies, opened up new market niches, improved health, promoted better agricultural policies, and prompted close networking at many levels to share skills and knowledge, build social capital, and enhance local capacity for research and production.

Economic Benefits

China imported mungbean valued at $13.6 million in 1986; in 2000, imports dropped to $1.4 million. The export of mungbean during the same period increased from $45 million to $50 million.

Pakistan's economic benefits from mungbean have been estimated to be around $20 million, of which substituting the area under local varieties with the improved varieties accounts for $5.3 million; increase in area with improved varieties is $3.6 million; improvement in quality is $4.4 million; and residual effect of mungbean on the following wheat crop is $6.4 million. Consumers' share of the benefits was 38 percent; and producers' share was 62 percent (Ali et al. 1997)[2].

A farm-level survey of 115 households in six provinces in the Northern and Central Plains of Thailand was conducted in April–May 1992. The key objectives of the survey were to obtain a detailed input–output characterization of mungbean cultivation in Thailand, assess the adoption of AVRDC-related mungbean technologies, and determine their profitability. The results clearly showed that more than 90 percent of the farmers surveyed grew the three improved varieties, KPS1, KPS2, and CN60 (46, 38, and 7 percent respectively). KPS1 and KPS2 were cultivated during the dry season, while KPS1 was preferred for the rainy season. The net return from mungbean cultivation in the dry season is low. In the rainy season, the net return is almost double that of the dry season (Jansen and Charnnarongkul 1992).

Policy Improvements

China has instituted four major reforms in its grain distribution system and mungbean is included in the system. The reforms are (1) to purchase surplus grain from farmers at protected prices; (2) to see that traders engaged in grain businesses operate on the basis of purchase price with a reasonable profit margin; (3) to earmark funds for purchasing grain from farmers for that specific purpose; and (4) to conduct the reform of grain enterprises rapidly. In 2001, China lifted controls in marketing areas. Since 1993 the mungbean futures market has operated successfully at the Zhengzhou Commodity Exchange (Huijie et al. 2003).

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[2] The analyses cited in Ali et al. (1997) include biases and assumptions that can be challenged. At the time of the study, the authors lacked the funds to collect panel data, but in the absence of such data, they neglected to use matching techniques to eliminate biases emanating from self-selection. A key parameter to estimate the producer/consumer surplus was the difference between growers of improved and traditional varieties in the cost per kilogram produced, calculated from the sample mean for each group. First, this estimate did not take into account systemic (nonrandom) factors for the difference between adopters of the improved variety and nonadopters, which could be correlated with performance and which would have caused farmers to have lower yield or higher unit cost even if they were to grow improved varieties. Second, the tests for statistical significance for the differences between the subgroups of growers were done at an 85 percent confidence level, which is not acceptable in economics research. A third deficiency is the attribution of the whole increase in mungbean area in Pakistan between 1986 and 1995 to incentives created by the new variety, a claim that is not substantiated. However, the best proof of success of the mungbean transformation—the increased rate of adoption of the improved varieties along with the rapid decline in the share of traditional varieties—is unquestionable. Farmers would adopt the improved variety only if it were significantly superior (Evenson and Gollin 2003). The long maturity duration of local varieties made them unsuitable for inclusion in wheat rotations, but improved varieties with short maturity duration and resistance to mungbean yellow mosaic virus did fit well into wheat rotations. To confirm the systemic benefits of the widespread adoption of improved mungbean varieties, formal impact studies need to be funded and carried out to obtain statistically valid results that can be disseminated in appropriate journals.

The Ministry of Agriculture, Government of Bangladesh approved the Lentil, Blackgram, and Mungbean Development Pilot Project (LBMDPP) in collaboration with DFID and AVRDC. The country's seed exchange program was funded primarily through the LBMDPP, which facilitated the rapid expansion in area of improved mungbean varieties. However, seed traders mixed local and improved varieties, and did not take sufficient care to maintain the seed purity of improved varieties. The LBMDPP is determined to see that the problem is rectified. The Ministry of Agriculture also organized a demonstration for women to prepare mungbean sprouts and other products from mungbean to help alleviate anemia in Bangladesh.

The presence of mungbean continues to grow in Punjab. The area to be planted with mungbean in the 2009 summer season is estimated at approximately 60,000–80,000 ha. A new strain, SML832, is currently being tested; this variety has medium-sized seed as requested by farmers, and Punjab Agricultural University hopes it will be released in 2010. Farmers are experimenting with selling small packets of seed at Rs 35–36/kg and are growing more mungbean for home consumption (T.S. Bains, personal communication).

Thailand's seed exchange program has played a major role in replacing the old local mungbean variety with the new improved varieties. Government policy limited the release of water for the dry season to prevent farmers from growing another rice crop, which forced the farmers to grow a non-rice crop such as mungbean. This in part accounted for the low mungbean yield in the dry season; farmers did not get enough water and did not provide sufficient inputs for a good yield. However, they received improved mungbean seed from the government because they were growing a nonrice crop (Jansen and Charnnarongkul 1992).

Enhanced Production

As of 2003, the Chinese National and Provincial Crop Review Committee released nearly 20 new improved mungbean varieties and extended them for large-scale planting throughout the country. The two improved varieties selected from AVRDC, Zhong Lu #1 and Zhong Lu #2, were planted to nearly 85 percent of the 772,000 ha in China (Huijie et al. 2003). Due to the release of the improved varieties, mungbean production in China increased at an annual rate of 2.4 percent from 1986 to 2000, primarily due to the increase in yield at the rate of 1.7 percent per year. The annual per capita consumption of mungbean in China increased from 0.3 kg to 0.5 kg from 1986 to 2000, and during the same period the share of mungbean in total pulse consumption increased from 14.2 percent to 28 percent.

Pulses, including mungbean, provide 20 to 30 percent of the protein requirement of India's population. Mungbean is cultivated in at least 18 states in India under diverse agroclimates and with cropping systems under marginal conditions (Tickoo and Satynarayana 1998; Grover et al. 2004). Improved mungbean has helped to diversify rice-wheat rotations in India. Disease resistant varieties with uniform maturity enabled farmers to use machines to harvest completely in a single harvest. In Punjab during the 2006 summer and rainy season, more than 95 percent and 60 percent of the area was planted to improved mungbean SML668 respectively (M.L. Chadha, personal communication). The area planted to mungbean increased from 23,000 ha in 2000–2001 (Grover et al. 2006) to more than 75,000 ha in 2002–2003 (Bains et al. 2006) due to the improved mungbean variety SML668. States neighboring Punjab benefited through the transfer of mungbean technology. For example, by the end of 2008 the area planted to SML668 in Rajasthan, Haryana, and Himachal Pradesh was estimated to be around 60,000, 70,000, and 50,000 ha respectively (M.L. Chadha, personal communication).

A detailed mungbean production survey in 1994 was conducted in the Pakistani Punjab. In total 250 representative farmers were selected at random for the study. Data on farm management practices, cropping patterns, input use, varietal adoption, cost and return, and production constraints in mungbean cultivation were collected using a detailed questionnaire. Survey results indicated improved mungbean varieties replaced 90 percent of the local varieties in 1994, compared with 20 percent in 1988; improved varieties gave nearly 55 percent higher yields than the local variety; the cost of production of wheat in wheat-mungbean was 23.5 percent less than wheat-other crop rotation; the benefit–cost ratio of improved mungbean ranged from 1.87 to 2.21, depending on the variety, compared with 1.31 for local varieties; and mungbean's share of total pulse area increased from 3 percent in 1980 to 11 percent in 1993–94 (Ali et al. 1997).[3]

In Tamil Nadu, the area under sugarcane is 316,000 ha; it was estimated that there is potential to add 150,000 ha with the improved short duration mungbean, Pusa Vishal (also called Pusa Bold) as an intercrop. In addition, Pusa Bold can be included in 38,000 ha of banana and 45,000 ha of cassava plantations as an intercrop (Muthiah 2006).

In 1980, Bangladesh had a mungbean production area of 15,000 ha, which produced 7,000 tons annually at 467 kg/ha. In 2000, the production area increased to 55,000 ha, and production increased to 36,000 tons annually at 654 kg/ha. The impressive growth is attributed to the introduction of improved varieties. Improved varieties have replaced local varieties on 70 percent of the mungbean area in Bangladesh. A socioeconomic survey of 320 farmers in the districts of Jessore, Barisal, and Dinajpur conducted in 2002–2003 showed about 50 percent of the farmers cultivated improved mungbean, and the farmers who grew mungbean consumed more mungbean (Weinberger et al. 2006).

With only a few grams of initial test material sent for trial in the early 1980s, Myanmar's local researchers and extension agents were able to move the promising selections to farmers and bring about significant change in agriculture and diets. Mungbean area in Myanmar in 1980–81 was 68,000 ha; it increased to 650,000 ha in 1997–2000.

Afghanistan has become the latest country to embrace mungbean. On April 15, 2009, H.E. Deputy Minister Mr. Mohammad Sharif formally released two improved mungbean varieties "Maash-2008" (NM 92) and "Mai-2008" (NM 94), developed from AVRDC lines, in Nangarhar province. Through its Alternative Development Program in Eastern Afghanistan, ICARDA, working in collaboration with Agricultural Research Institute of Afghanistan (ARIA), Ministry of Agriculture, Irrigation, and Livestock (MAIL), and AVRDC has been evaluating these varieties for the past four years in nine locations of three eastern provinces (Kunar, Laghman, and Nangarhar), and in the northern province of Kunduz. Both the new varieties are short duration and high yielding compared to other currently grown varieties in Afghanistan. These varieties, which mature about 10 days earlier than the local variety, yield 50 to 60 percent more than all local varieties and also produce 30 percent more than the highest-yielding existing improved variety.

Health and Nutritional Benefits

Research at AVRDC has shown the value of mungbean in terms of iron intake (AVRDC 1997 1999; Yang and Tsou 1998.) Weinberger (2003b) conducted a survey in Lahore, Pakistan with 200 working women using a seven-day food recall from June 2001 to February 2002. The results of the study showed hemoglobin levels in the blood as one of the major determinants of productivity. Based on the increase in mungbean production due to improved varieties reported (Ali et al. 1997) and the higher iron content of the improved mungbean varieties (6.0 mg vs. 3.5 mg for the local varieties) (Vijayalakshmi et al. 2003), the productivity increase of anemic female workers with increased iron availability due to improved varieties was estimated to be $3.5 to 4.2 million annually (Weinberger 2003a, 2003b).

The Avinashilingam Home Science University for Women in Coimbatore in South India and Punjab Agricultural University addressed the health and nutritional benefits of mungbean, especially to alleviate anemia. Two women postdoctoral scientists worked at the AVRDC Biochemistry and Nutrition Laboratory under the guidance of Dr. Samson C.S. Tsou and developed improved recipes using mungbean and other ingredients. The recipe books published in Punjabi and English help rural and urban women across North India prepare nutritious food to improve the bioavailability of iron and alleviate malnutrition in family diets (Subramanyan and Yang 1998; Bains et al. 2003).

A feeding trial with 225 boys and girls of ages 10 to 12 was held for one year in Coimbatore to determine the role of the mungbean recipes in improving the children's iron status and the hemoglobin

[3] See footnote 2.

levels, and how the additional iron affected the physical and mental status of the children. The improved mungbean variety had twice the iron content, 6 mg compared with 3.5 mg for the local variety. The results showed that supplementing diets with mungbean dishes prepared with improved high-iron recipes did improve overall physical stamina. However, it is likely that the overall higher availability of energy and protein to these children also may have contributed to their improved physical stamina. Enhancing iron bioavailability through improved recipes for local dishes is a cost-effective way of improving iron nutrition in population groups at risk. Both in Coimbatore and Punjab, education and demonstrations have been very effective in bringing about change in food preparation practices to enhance the bioavailability of iron in the diet (Vijayalakshmi et al. 2003; Bains et al. 2006)

Sustaining Soil Productivity

As a legume crop, mungbean has the ability for biological nitrogen fixation. Growing mungbean is reported to benefit the succeeding cereal crop. Meelu and Morris (1988) reported that incorporation of mungbean residues gave a rice yield increase equivalent to 25 kg N fertilizer per hectare. Research results in Punjab have shown that the extra-short duration SML668 mungbean, which fits well between wheat and rice as a catch crop, leaves a residual of 33–37 kg N/ha for the succeeding crop after meeting its own requirement. This additional nitrogen provides about 25 percent of the N requirement of the succeeding crop (Sekhon et al. 2007).

Guaranteed prices for cereals and subsidized inputs offer little incentive for farmers to diversify the rice-wheat cropping system. Intensive cereal cropping has resulted in response to a decline in partial factor productivity of nitrogen fertilizer (Hobbs and Morris 1996). Crop diversification is the key to reversing declining crop productivity (Pingali and Shah 1999). A survey of 200 farmers in four ecological regions in Punjab, with 75 adopting the improved mungbean variety SML668, was conducted in 2002. The Cobb-Douglas production function was used to estimate the parameters. The net returns per ha for the rotation using wheat-mungbean-rice was $235 compared to rice-fallow-wheat (Weinberger 2003a). The increase was due to the residual nitrogen available to the succeeding crop, which increased yield. The total net return from the rice-wheat rotation including mungbean was 27 percent higher than the rotations without mungbean. Assuming that the 1 million ha currently under rice-wheat rotation can include mungbean, the total rice yield would have increased by 450,000 t, valued at $50.7 million in additional income for farmers in the Indo-Gangetic Plains in India (Weinberger 2003a).

Access to the Processing Value Chain

Mungbean is used for making transparent noodles and vermicelli throughout Southeast Asia (Maneepun 2003). Mungbean noodles are a high-value, processed commodity. Research to improve the manufacture of mungbean noodles and other processed mungbean products would help increase the value of mungbean in Thailand and the region. Mungbean sprouts are a popular vegetable in Southeast Asia, China, and Taiwan. The hardness of the seed coat affects the quality and quantity of mungbean sprouts. The hard seed trait is complex and influenced by a number of factors; while there is some evidence that bold seeded-varieties have fewer hard seeds than small-seeded varieties (Sekhon et al. 2006), further research into this trait would be useful in developing improved mungbean varieties for fresh market sprouts.

In South Asia mungbean is processed into *Dhal.* The husk and bran are removed by milling. After milling, approximately 73.9 percent *Dhal* is recovered; the husk and bran account for 18.45 percent, and the milling loss is 7.60 percent (Amiruzzaman and Shahjahan 2006). The maximum recovery of *Dhal* by modern methods could be increased to 89.5 percent (Singh 2006). In other grain legumes such as pigeonpea and chickpea, the recovery from varieties with large grain size is higher than from varieties with small grain size. Improved mungbean varieties have larger grain size. It is not known whether the milling recovery percentage for improved mungbean varieties is better than that of traditional varieties. However, improvements in milling are likely to increase marketable yield and add value to the crop, which can help stabilize mungbean prices.

Building Capacity

The Chinese Academy of Agricultural Sciences (CAAS) led research on mungbean in cooperation with institutes from 25 other provinces in the seventh and eighth Five-Year Plans, from 1986 to 1995. The total number of researchers committed to mungbean included 30 from the Crop Germplasm Resources and 70 from other institutions. CAAS has cooperated with AVRDC since 1983 and four of its researchers were trained at AVRDC's Asian Regional Center in Thailand. CAAS also founded the Association of Mungbean Research, establishing a strong base for mungbean research and development in China (Institute of Crop Germplasm Resources 1993; Cheng 1996; Institute of Crop Germplasm Resources 1999).

The Seed Village Program launched in Punjab, India has spread to other Indian states. From 15 tons of SML668 seed in 2001, Punjab increased seed production to approximately 810 tons in 2002 and 6,950 tons in 2003. Under the umbrella of the Seed Village Program, 600 seed kits were distributed to 600 farmers to plant 600 acres with mungbean in Punjab, Rajasthan, and Bihar from 2005 to 2008; the program has generated 17,000 tons of seed to date (M.L. Chadha, personal communication). Since 2005, AVRDC has organized 15 field days and 1,200 demonstrations for more than 4,000 farmers, extension specialists, rural women and schoolgirls to promote mungbean cultivation, which has raised awareness of improved mungbean.

To promote the improved mungbean varieties in Bangladesh 11,280 demonstrations were conducted in 47 *upazillas* (subdistricts) in 15 districts. Average yields of demonstration plots (1110 kg/ha) were 54–56 percent higher than the national average (705 kg/ha) (Afzal et al. 2006). To ensure self-sufficiency in pure, quality seed of improved varieties, Bangladesh followed two approaches: 1) a seed exchange program from 2002 to 2004, in which improved seed was given to farmers in exchange for an equal quantity of local variety to the government; and 2) adopting the Seed Village Program initially launched in Punjab, India. In 2000–2001 the total quantity of seed produced of six improved varieties was 1,074 t. Seed production increased to 11,538 tons in 2002–2003. Assuming only 25 percent of the seed is used for planting, the amount produced was sufficient to cover the whole mungbean area in Bangladesh (Afzal et al. 2006).

Of Special Note: Nepal and Sri Lanka

Normal impact assessment and economic studies could not be conducted in Nepal and Sri Lanka due to political strife, lack of personnel, and lack of sufficient resources. However, demand for mungbean is rising in Nepal. Collaboration with AVRDC resulted in the release of three varieties and the country's mungbean area under them is increasing steadily. The immediate intervention issue in these post-conflict countries is seed availability and access to good quality seeds (Erskine and Nesbitt 2009). Mungbean forms an important component of a new DFID-funded project in Nepal entitled "Innovation Challenge Fund of Research into Use Programme." In this project, Nepal plans to multiply seed in 18 out of 21 districts of Nepal Terai and hopes to produce substantial seed in the 2009 summer season, which will be used to scale out mungbean cultivation in subsequent seasons (K.D. Joshi, personal communication). Collaboration with private sector NGOs in Nepal is vital for the success of the program.

In Sri Lanka the total area under mungbean in 1980 was 14,200 ha, production was 12,900 tons and yield at 908 kg/ha. In 1995, production area rose to 33,200 ha, production increased to 26,400 t, but yield declined to 795 kg/ha. The improved varieties have encouraged more farmers to plant mungbean (Weinberger 2003a). However, the latest data on area and production of mungbean are unavailable.

4. SUSTAINABILITY OF THE MUNGBEAN TRANSFORMATION

Bangladesh, Bhutan, China, India, Myanmar, Nepal, Pakistan, Sri Lanka and Thailand have a very strong commitment from their governments to continue, strengthen, and sustain the gains made from the introduction of improved mungbean lines. The impact of improved mungbean and associated technologies on the benefit–cost ratio and the IRR has been demonstrated and governments have taken note; sufficient staff and fiscal resources are now allocated to mungbean research and development activities in these countries. The national agricultural research systems (NARS) scientists are focusing on location-specific management technologies and mechanisms to effectively produce and distribute pure, reliable good-quality seed for farmers at the right time in the right quantities.

The most important policy required to sustain the scale-up of mungbean is for governments to assure a market and a stable price that can bring farmers reasonable profit in relation to competing crops. For example, in some areas of the Indo-Gangetic Plains replacing rice with mungbean in the rainy season is not profitable, because mungbean yields are not high enough. However, if a summer crop of mungbean and a rainy-season crop are taken together, the return for investment is very attractive for the farmer, with the added benefit of preventing excess drawdown of the water table, soil salinization, and depletion of soil nutrients from cereal–cereal fatigue (Grover et al. 2004). Government policy should guarantee mungbean prices and provide support for inputs. China has instituted such policies and they are working efficiently.

The Pakistan Agricultural Research Council (PARC), with external support, continues the development and promotion of new improved MYMV-resistant varieties. The major problem is the lack of good-quality seed. Pakistan's agricultural authorities need to address this situation and institute appropriate policies to meet the need. In Myanmar, the FAO's 2002–2003 Technical Cooperation Program Project, "Improved Grain Legume Production Technologies" was extended for one more year and completed in 2004. The Myanmar government and the farmers have refined and extended the benefits of improved varieties. For Nepal, DFID is providing support for the country to continue the work started by AVRDC. AVRDC continues to provide technical assistance whenever it is needed. In India, AVRDC's Regional Center for South Asia collaborates with Punjab Agricultural University and the states of Bihar, Haryana, Himachal Pradesh, Jharkhand, Rajasthan, Tamil Nadu, and Uttar Pradesh to expand the area and production of improved mungbean varieties adapted to these locations and the program is making significant progress.

In all these countries, scientists should be brought together once every two to three years to discuss the current status of mungbean, raise concerns and issues, and develop solutions to sustain the progress made so far. Training for new and current staff will assure further progress. Funds from external sources will be required for these activities, as national programs do not provide this type of support.

For South Asia, a technical assistance project combined with a developmental component to spread the improved varieties, a nutritional component to educate and extend the improved bioavailability of iron with improved mungbean, and an economic component to assess the impact of the above activities for three to five years would be very valuable to sustain the momentum generated at present.

To ensure the sustainability of the Mungbean Transformation, the authors recommend partners take note of the following:

- *Research gaps:* Insect pests (especially *Melanagromyza sojae, Ohiomia centrosematis, Etiella zinckenella, and Callosobruchus chinesis)* and powdery mildew disease are major problems limiting mungbean production in many areas. In the Indian state of Karnataka, for instance, powdery mildew disease is a problem that severely curtails productivity. Partners should focus their attention on these issues to ensure previous achievements can be sustained.
- *Seed policy:* Lack of improved, good quality, pure seed in sufficient quantity at a reasonable price was one of the major drawbacks preventing the rapid expansion of mungbean in area and

production. Private seed companies are keen to collaborate with national and international research institutes on vegetable crops research, so that they can obtain improved germplasm and produce seed to market to farmers; however, few private seed companies seem interested in the market potential for improved legumes. Government policies should encourage and promote improved varieties, and efforts should be made to encourage private seed companies to engage in legume seed production and distribution.

- *Exploiting the potential:* For the improved varieties to perform to their full potential, appropriate seasonal and location-specific agronomic practices should be refined. Improved agronomic practices should reduce farmers' cost of production, increase their net profit, sustain soil productivity, and not harm the environment.
- *Select for resistance:* Biotechnology can be used to speed up selection for MYMV resistance. Recently, Chen (2007) used 200 recombinant inbred lines from a cross between bruchid-resistant wild species TC 1966 (*V. radiata* var. *sublobata* [Roxb.] Verdc.) and MYMV-resistant NM 92 to identify molecular markers for bruchid resistance and MYMV. The study successfully identified four random amplified polymorphic DNA markers for bruchid resistance (Chen et al. 2007). The study also found six amplified polymorphic DNA and four cleaved amplified polymorphic DNA markers related to MYMV resistance. These markers will be valuable in selecting mungbean to improve breeding efficiency and to sustain the development of new MYMV-resistant lines.
- *Combating stress:* Drought and flooding affect the performance of improved varieties. Varieties should be developed that can withstand adverse conditions to stabilize yield.
- *Price policy:* Farmers' organizations were concerned with fluctuating prices for mungbean. Governments should develop guidelines and if necessary guarantee mungbean prices, which will encourage farmers to include the legume to diversify cereal cropping systems. Plant breeders can focus on processing traits to enhance the value of the processed products, which can help stabilize prices.
- *Expanding the scope:* Research on improving production should go hand-in-hand with studies in marketing, economics, and nutrition to ensure traders and consumers accept the improvement and that it is beneficial for those people most in need.
- *Making impact analysis meaningful:* Include innovative and indirect forms of impact along with traditional consumer and producer surplus studies and publish them in high-quality journals to explain the intervention's value to policy makers and donors.

5. LESSONS LEARNED

The participating partners learned many lessons from the rollout of mungbean, including the need for active commitment; the importance of eliciting the help of others to test and extend technologies; the value of hands-on experience for convincing farmers to adopt new varieties; and the vital role of government at all levels in creating policies to support research and promote the practical application of research results. Other lessons include

1. *Commitment:* The strong commitment of all parties—international research institutes, national partners, donors, NGOs, individual farmers—was needed for the intervention to succeed.
2. *Plan with a purpose:* A realistic, definite goal and specific plans based on available resources helped the intervention move forward.
3. *Keep track of time:* Deadlines were set for achieving goals. Progress was monitored semiannually and annually, which allowed the project participants to make mid-course adjustments as needed in the work plan.
4. *Focus on farmers:* Crop management practices varied in each country and season. NARS developed farmer-friendly technology to address the farmers' specific constraints in their countries.
5. *Understand differences:* Progress and success varied between countries, and within a country between different provinces or states. For instance, Punjab in India was able to make rapid progress in seed production and distribution; Bangladesh was able to adopt and follow the example of Punjab. Within India, Rajasthan, Bihar, Haryana, Himachal Pradesh, and Jharkhand made good progress with assistance from Punjab. Success in one area can serve as a catalyst for success in neighboring states and countries.
6. *Welcome all contributions:* Countries had different strengths and weaknesses, but even small countries were able to contribute to the overall good. China and India are big countries and they have sufficient resources to maintain a large germplasm collection and conduct meaningful research to accomplish the goal. However, smaller countries made significant contributions to the intervention's success: The Philippines developed high-yield, early maturing, bold-seeded varieties; Pakistan developed lines with a high level of resistance to MYMV.
7. *Share across boundaries:* Sharing resources between countries and within a country among states is the best way to rapidly spread technology and improve productivity, nutrition, and food security. Partners were able to share their technology through formal networks like SAVERNET and informal networks like the ones with China and Pakistan. Sharing without reservations helped to achieve the accomplishments in mungbean.
8. *Adapt as needed:* Evaluating improved technology regardless of its source and determining if it was suitable for local situations returned big dividends with a small investment in Myanmar.
9. *Educate for the future:* Training was essential for researchers, extension staff, farmers and economists to systematically organize, plan, and implement the activities and collect data.
10. *Seeing is believing:* Demonstration trials, farmers' field trials, and field days enabled farmers to see for themselves the performance of the improved varieties compared to local varieties. When farmers actively participated in research and development efforts, they felt that they had ownership in the output. They accepted the responsibility and did the job with dignity and pride.

11. *Involve the community:* The Seed Village Program and other seed exchanges proved to be excellent vehicles to rapidly expand mungbean area and production and were adapted for use in several countries.
12. *Set the example:* The success of improved mungbean in Punjab in India opened the eyes of neighboring states such as Bihar and Rajasthan, etc. and neighboring countries, such as Nepal.
13. *Let others help:* NGOs played an important role in extending technology to the farmers.
14. *Promote the benefits:* The return on investment to the farmer is extremely important for the success of any new variety. Farmers need to understand why maintaining pure seed of the improved variety is worthwhile.
15. *Include hands-on training:* To enhance nutritional security, women received training in mungbean preparation to ensure valuable nutrients would not be lost during cooking.

In many countries, there are strict rules and regulations governing the release of new improved varieties. However, the official release of a variety does not guarantee that farmers will cultivate it. We learned that several important benchmarks must be met for successful adoption:

1. Farmers need to be convinced of the variety's superior performance.
2. Pure seed of the improved variety must be available at a reasonable price in sufficient quantities in time for farmers to plant.
3. The management technologies associated with the improved variety in specific locations need to be defined and made available as a package to farmers.
4. National policies and government institutions must be committed to extend the technology to farmers.

International centers need to be sensitive in working with national partners. NARS should be credited appropriately for their effort. IARCs should work behind the scenes, providing technology and other support unavailable to the NARS. The National Bureau of Plant Genetic Resources (NBPGR) in each country has a set of rules and regulations; IARC scientists should follow them carefully to avoid delays. Each country has their own variety release policy; by working closely with NARS partners, it was possible to convince them make minor modifications to facilitate the rapid movement of highly promising materials to farmers.

6. CONCLUSION

From our perspective, only ongoing involvement from all partners will ensure the mungbean transformation address needs relevant to current and evolving conditions. For instance, for the improved varieties to perform to their full potential, appropriate seasonal and location-specific agronomic practices must be refined. In light of climate change, improved varieties must be developed to withstand continuously evolving diseases, insects, drought, and flooding. Innovative and indirect forms of impact assessment should supplement traditional consumer and producer surplus studies to explain the intervention's value to policy makers and donors.

The world population is expected to reach 8 billion within the next 10 years, and more than half of that population will be in Asia. Despite rising incomes in China and India, food and nutritional security continue to be a concern across the continent. Protein, calorie, and micronutrient deficiencies affect almost 2 billion people in the region (Ali et al. 1997). In 2000, vegetable sources provided 49.8 g protein per capita per day in Asia, compared with 21.2 g from animal sources. It may be a "slow runner" but mungbean—a nitrogen-fixing, protein- and iron-rich legume—will undoubtedly play an ever-growing role in Asian diets as governments seek to enhance food security and sustain their agricultural base. Through continuing research cooperation among local, national, and international partners to improve and share mungbean germplasm and technical expertise, small-scale farmers can increase yield, diversify crop rotations on more than 25 million ha under rice-wheat cropping systems (Abrol et al. 1997; Timsina and Connor 2007) and increase their incomes by growing this nutritious legume for their families and communities.

APPENDIX. SUPPLEMENTARY TABLES

Table A1. AVRDC mungbean cultivars released in nine countries, January 2009

No.	Local name	AVRDC ID#	Parentage	Year released	Country
1	BARI Mung-5	NM 92	VC 2768B x VC 6141-36	1997	Bangladesh
2	BU Mug 1	VC 6372(45-8-1)	VC 6370-92 x [VC 2768A x (VC 1973A x V 6601)]	2000	Bangladesh
3	BU Mug 2	VC 6370(30-65)	VC 2768A x VC 6141-36	2001	Bangladesh
4	KPS 1	VC 1973A	CESID-21 x EG-MG-16	2001	Bhutan
5	-	BARI Mung-2	VC 2768A x VC 6141-36	2002	Bhutan
6	KPS 2	VC 2768A	VC 1481A x VC1628A	2002	Bhutan
7	Xujin #1	VC 1973A	CESID-21 x EG-MG-16	1985	China
8	Xu Yin No. 1	VC 1973A	CESID-21 x EG-MG-16	1985	China
9	Zhong Lu #1	VC 2971A	VC 1089A x V 1945	1986	China
10	Yue Yin #2	VC 1973A	CESID-21 x EG-MG-16	1986	China
11	Zhong Lu #1	VC 1973A	CESID-21 x EG-MG-16	1986	China
12	DX 102A	VC 2768A	VC 1481A x VC1628A	1986	China
13	V 2917	VC 2917A	VC 2790 x VC VC 2745	1989	China
14	Su Lu #1	VC 2768A	VC 1481A x VC1628A	1989	China
15	V 1381	VC 1381	V 1859 x V 1250	1989	China
16	Elu #2	VC 2778A	VC 1560C x VC 1628A	1989	China
17	Su Lu No. 1	VC 1973A	CESID-21 x EG-MG-16	1989	China
18	Ji Lu NO. 1	VC 2917A	VC 2790 x VC VC 2745	1989	China
19	ER Lu No. 2	VC 2778A	VC 1560C x VC 1628A	1989	China
20	VC 2917A	VC 2917A	VC 2790 x VC VC 2745	1991	China
21	VC 1381	VC 1381	V 1859 x V 1250	1991	China
22	Yu Lu No. 2	Local x VC 1562A		1994	China
23	Yue Yin #1*	VC 2768A	VC 1481A x VC1628A		China
24	Ji Lu No. 2*	Local x VC 2719A			China
25	Nan Lu No. 1*	V 1381	MG-50-10A(G)		China
26	Xu Yin No. 1	VC 2768A	VC 1481A x VC1628A	1989	China
27	M 986	V 3554	VC 2719 x VC 2723A	1981	India
28	SML668	NM 94	VC 6371-94 = VC 2768A x VC 6141-36	2000	India
29	Pusa Vishal	NM 92	VC 2768B x VC 1973A x VC 6601)	2000	India
30	Pant Mung 5	VC 6368(46-40-4)	VC 6370-92 x VC 6141-96	2002	India
31	Pusa 105	VC 1137-2-B	VC 1025 x VC 1000	1984 1983	India
32	Pusa 101	V 3484	VC 2633 x VC 1177B	1984 1983	India
33	Yezin-5+				Myanmar
34	Yezin-7+				Myanmar
35	Yezin-8+				Myanmar
37		VC 1973A+		2000	Myanmar
38	KPS-1	VC 3960-88		2002	Nepal

Table A1. (Continued)

No.	Local name	AVRDC ID#	Parentage	Year released	Country
39	Kalyan	NM 94	VC 6371-94 = VC 2768A x VC 6141-36	2006	Nepal
40	Prateeksha	VC6372	VC 6370-92 x VC 6371-93	2006	Nepal
41	NIAB MUNG 54	VC 6141-54	VC 1973A x 6601 F21 Gammary treated	1990	Pakistan
42	NIAB MUNG 51	VC 6370-92	VC 1973A x 6601 F1 Gammary treated	1990	Pakistan
43	NM 92	VC 6370-92	VC 2768B x VC 6141-36	1992	Pakistan
44	NIAB MUNG 92	VC 6370-92	VC 2768B x VC 6141-36	1996	Pakistan
45	NM 51	VC 6370-92	VC 1973A x V6601	1990	Pakistan
46	NM 54	VC 6141-54	VC 1973A x V6601	1990	Pakistan
47	Type 77	VC 1131-B-12-2-B	EG-MG-16 x ML-3 x EG-MG-16	1982	Sri Lanka
48	MI-6	VC 6173B-20G	VC 1560A x VC 6370-92	2004	Sri Lanka
49	KPS II	VC 2778A	BPI glabrus 3// CES 44/ ML 3 /// CESID-21/ PHLV8)	1986	Thailand
50	KPS 1	VC 1973A	CESID-21 x EG-MG-16	1986	Thailand
51	Chai Nat 60	VC 1178	MG50-10A (Y) x ML-6	1987	Thailand
52	PSU 1	VC 2768A	VC 1481A x VC1628A	1988	Thailand
53	Chai Nat 36	VC 1628A	V 3476 x V 2184	1991	Thailand

VC = *Vigna* Crossbred line from AVRDC.
V = accession or introduction.
+ = local name, AVRDC ID #; parentage or year of release unavailable.
* = year of release unavailable.

Source: AVRDC Genetic Resources and Seed Unit (GRSU)

Table A2. Seed multiplication and area expansion of VC 1973A in China, 1985-87

Location	Year/Season	Area planted (ha)	Qty of seed sown (kg)	Seed harvested (t)
Sheqi, Henan	1985 Spring	0.3	3.5	0.650
Sheqi Henan	1985 Summer	12	650	12
Nanyang, Henan	1986 Summer	26.7	-	70
Nanyang, Henan (8 counties)	1986 Autumn	982.4	-	1,500
Henan	1987	20,000		

Source: Lin and Cheng 1988. - Amount sown unknown.

Table A3. Varieties included for summer trial and total seed quantity sent to each site

Entry name/number	1,000-seed wt. (g)	Original source	Amount (g)	Total seed quantity for 4 replications (g)
BARI Mung 2	31.4	Bangladesh	16 x 4	64
BARI Mung 4	31.5	Bangladesh	16 x 4	64
Bina Mung 2	34.4	Bangladesh	17 x 4	68
Harsha	45.8	Sri Lanka	22 x 4	88
KPS 2	57.7	Thailand	28 x 4	112
NM-92	47.4	Pakistan/AVRDC	23 x 4	92
NM-94	52.1	Pakistan/AVRDC	26 x 4	104
PDM-11	27.8	India	14 x 4	56
PDM-54	29.1	India	14 x 4	56
SML-134	32.0	India	16 x 4	64
SML-32	34.7	India	17 x 4	68
VC 6173B-10	68.1	Pakistan/AVRDC	33 x 4	132
VC 6368 (46-40-4)	52.4	Pakistan/AVRDC	26 x 4	104
VC 6369 (53-97)	50.5	Pakistan/AVRDC	25 x 4	100
VC 6370-30-65	51.8	Pakistan/AVRDC	25 x 4	100
VC 6370A	57.4	Pakistan/AVRDC	28 x 4	112
Local check				

Source: Shanmugasundaram 2004.

Table A4. Varieties included for rainy season trial and total seed quantity sent to each site

Entry name/number	1,000-seed wt. (g)	Original source	Amount (g)	Total seed quantity for 4 replications (g)
BARI Mung 2	31.4	Bangladesh	16 x 4	64
Basanti	30.2	India	15 x 4	60
CN 9-5	60.8	Sri Lanka	30 x 4	120
CO-3	31.2	India	15 x 4	60
KPS #1	61.2	Thailand/AVRDC	30 x 4	120
KPS #2	57.7	Thailand/AVRDC	28 x 4	112
MIMB-101	49.9	Sri Lanka	24 x 4	96
ML-267	31.1	India	15 x 4	60
ML-613	34.4	India	17 x 4	68
NM-54	65.1	Pakistan/AVRDC	32 x 4	128
NM-92	47.4	Pakistan/AVRDC	23 x 4	92
Pusa 9072	31.6	India/AVRDC	16 x 4	64
VC 3960-88	48.6	AVRDC	24 x 4	96
VC 6153B-20G	66.3	Pakistan/AVRDC	32 x 4	128
VC 6153B-20P	54.0	Pakistan/AVRDC	26 x 4	104
VC 6173B-6	69.0	Pakistan/AVRDC	33 x 4	132
VC 6372(45-8-1)	48.8	Pakistan/AVRDC	24 x 4	96
Local Check				

Source: Shanmugasundaram 2004.

Table A5. List of cultivars used in the summer season trial

Code	Cultivar name	Source
1	BARIMUNG 2	BARI, Bangladesh
2	BARIMUNG 2	BARI, Bangladesh
3	BARIMUNG 4	BARI, Bangladesh
4	PDM-11	IIPR, India
5	SML-32	PAU, India
6	SML-134	PAU, India
7	PDM-54	IIPR, India
8	VC 6370-30-65	Pakistan/ AVRDC
9	NM-92	Pakistan/ AVRDC
10	NM-94	Pakistan/ AVRDC
11	VC 6368-46-44	Pakistan/ AVRDC
12	VC 6369-53-97	Pakistan/ AVRDC
15	VC 6173B-10	AVRDC
16	Harsha	Sri Lanka

Note: Entries 13 and 14 from the original list are not included, because several locations did not include them in their trials.

Source: Shanmugasundaram 2004.

Table A6. List of cultivars used in the rainy season trial and their origin

Code	Cultivar	Source
1	BARIMUNG 2	BARI, Bangladesh
2	ML 267	PAU, India
3	ML 613	PAU, India
4	CO 3	Coimbatore, India
5	Pusa 9072	IARI, India
6	Basanti	IIPR, India
7	VC 6153B-20G	AVRDC, Taiwan/Pakistan
8	CN 9-5	Sri Lanka
10	VC 6173B-6	AVRDC, Taiwan
11	VC 6372(45-8-1)	AVRDC, Taiwan
12	VC 6141-54	AVRDC, Taiwan
13	VC 6370-92	AVRDC, Taiwan
14	MIMB 101	Faisalabad, Pakistan
15	VC 3960-88	AVRDC, Taiwan
16	KPS 1	KU, Thailand
17	KPS 2	KU, Thailand

Source: Shanmugasundaram 2004.

Table A7. Details of locations, latitude, and dates of planting of summer trial, 1999-2000

Country	Code	Location	Latitude	Season	Date planted
Bangladesh	B2	Ishurdi	24^{o}	-	- 2000
	G1	Gazipur	28^{o}	Rainy I	11 Mar 1999
	G2	Gazipur	28^{o}	Summer	- 1999
	G3	Gazipur	28^{o}	Rainy I	14 Mar 2000
	IS	Ishurdi	24^{o}	Rainy I	14 April 1999
	MY	Mymensingh	25^{o}	Summer	1 Mar 1999
Bhutan	BT	-	-	-	3 June 1999
India	BV	Bhavanisagar	11^{o}	Rainy	20 July 1999
	CO	Coimbatore	11^{o}	-	28 Dec 1999
	PJ	Punjab	30^{o}	Summer	12 Apr 1999
	P2	Pantnagar	29^{o}	Spring	14 Mar 2000
	P1	Pantnagar	29^{o}	Rainy	31 July 1999
Pakistan	FA	Faisalabad	31.5^{o}	Spring	23 Mar 1999
	IL	Islamabad	34^{o}	Spring	21 Apr 1999
Sri Lanka	SL	Maha Illuppallama	7^{o}	Dry	6 May 1999
Taiwan	T2	AVRDC	23^{o}	Spring	24 Feb 2000
	T9	AVRDC	23^{o}	Spring	24 Feb 1999

Source: Shanmugasundaram 2004.

Table A8. Details of locations, latitude, and dates of planting of rainy season trial, 1998-99

Country	Code	Location	Latitude	Season	Date planted
Bangladesh	GZ	Gazipur	28o	Rainy II	12 Sept 1998
	M1	Mymensingh	25o	Rainy II	28 Sept 1998
Bhutan	B1	Lingmethang	29	-	- 1998
	B2	Lingmethang	29		5 Aug 1999
India	HI	Hissar	29	Rainy	6 Aug 1999
Nepal	NP	Rampur chitwan	27	Rainy	23 Aug 1998
Pakistan	F1	Faisalabad	315’	Summer	24 July 1998
	F2	Faisalabad	315’	Rainy	9 July 1999
	I1	Islamabad	34	Rainy	22 July 1998
	I2	Islamabad	34	Rainy	20 July 1999
Sri Lanka	S1	Maha Illuppallama	7	Wet	18 Nov 1998
Taiwan	T1	AVRDC	23	Summer	22 July 1998
	T2	AVRDC	23	Summer	28 June 1999
	T3	AVRDC	23	Autumn	2 Sept 1999

Source: Shanmugasundaram 2004.

Table A9. Number of trials conducted by different countries in different seasons in different years, 1998-2000

	Planting months									
	1998			1999			2000			
Countries	March[1/]	July[2/]	Sept.[3/]	March[1/]	July[2/]	Sept.[3/]	March[1/]	July[2/]	Sept.[3/]	Total
Bangladesh	1		4	4		2	6			17
Bhutan	1			1	1	2			3	8
India				1	6	4	3	1		15
Nepal			1	1						2
Pakistan		2		2	2					6
Sri Lanka			2	3			5			10
AVRDC	1	1		1	1		1	1		6

[1/]March: Summer season
[2/]July: Rainy season
[3/]September: Dry season

Source: Shanmugasundaram 2004.

Table A10. The list of participants trained in the short course at AVRDC

Country	Name	Educational qualification	Age
Bangladesh	Dr. Abdul Hamid	Ph.D.	48
	Mr. Zia Uddin Ahmed	M.Sc.	49
	Mr. Md. Omar Ali	M.Sc.	33
	Mr. A.N.M. Manzoor Murshed	M.Sc.	33
Bhutan	Mr. Tayan Raj Gurung	B.Sc.	37
India	Dr. Wanjari Keshao Balabhar	Ph.D.	49
	Dr. Joginder Singh Brar	Ph.D.	54
	Dr. Naresh Chandra	Ph.D.	51
	Dr. Chandragiri Cheralu	Ph.D.	40
	Dr. Sharda Presad Mishra	Ph.D.	54
	Dr. A.R. Muthiah	Ph.D.	45
	Dr. Banwari Lal Sharma	Ph.D.	53
Nepal	Dr. Madhav Joshi	Ph.D.	40
Pakistan	Mr. Muhammad Zubair	M.Sc.	42
	Mr. Muhammad Saleem Chaudhary	M.Sc.	53
Sri Lanka	Mrs. Edirimanna Rallage Shiromani Priyangika	B.Sc.	33

Source: Shanmugasundaram 2004.

Table A11. Locations selected for the mungbean multilocation experiments

Country	Institute	No. of locations
Bangladesh	Bangladesh Agricultural Research Institute/Rampur Regional Research Station (summer season)	4
	Bangladesh Agricultural Research Institute /Ishurdi Regional Research Station (*Kharif* season)	1
Nepal	Nepal Agricultural Research Council, Kathmandu	1
Bhutan	Khangma Regional Research Station	1
Pakistan	Pakistan Agricultural Research Council/Nuclear Institute for Agriculture and Biology	2
Sri Lanka	Maha Illuppallamma Field Crops Research & Development Institute	1
India	Punjab Agricultural University, Ludhiana	1
	Indian Institute of Pulses Research, Kanpur	1
	Indian Agricultural Research Institute, New Delhi	1
	Tamil Nadu Agricultural University, Coimbatore	1
	Andhra Pradesh Agricultural University, LAM	1
	GB Pant University, Pantnagar	1
	Punjabrao Krishi Vidyapeth/ Maharashtra, Akola	1

Source: Shanmugasundaram 2004.

Table A12. Seed production of new varieties and promising lines for farmers' adoption, 2002

Country	Variety Name or Line No.	Quantity of seed produced (kg)	Area covered (ha)
Bangladesh	BARIMUNG 5 (NM-92)	7,800	150
	BUmug #1 (VC 6372-45-8-1)	2,500	50
India	Pusa Vishal (NM-92)	10,000	250
	NM-94	5,000	100
	VC 6173B-10	100	2
	VC 3960-88	100	2

Source: Shanmugasundaram 2004.

Table A13. Economic performance of improved mungbean varieties in farmers' fields in Bangladesh, 2002

Indicators	Demonstration	Farmers' management	Change (%)
Yield (kg/ha)	1,225	956	28.13
Gross return ($/ha)	554.00	416.00	33.23
Gross cost ($/ha)	240.00	191.00	26.31
Gross margin ($/ha)	314.00	225.00	39.36
Benefit-cost ratio	2.31	2.18	5.36

Source: Afzal and Bakr 2002.

Table A14. Seed production of SML668, summer 2002

Agency	Quantity (t)
Punjab Agricultural University seed farms	20
PUNSEED (Punjab State Seed Corporation)	50.4
National Science Council	6
Private agencies	20
Pulses Section, Punjab Agricultural University	8
Directorate of Extension Education, Punjab Agricultural University	10
Progressive farmers	40
Seed kits distributed to 3,500 farms by Punjab Agricultural University at Kishan Mela	190
Total	344.4

Source: Bains et al. 2006.

Table A15. Seed production of SML668, rainy season 2002

Agency	Quantity (t)
Punjab Agricultural University seed farms	60
Private agencies	50
Pulses Section, Punjab Agricultural University	5
Progressive farmers	50
Seed kits distributed to 3,500 farms by Punjab Agricultural University	300
Total	465

Source: Bains et al. 2006.

Table A16. Seed production of SML668, summer 2003

Agency	Quantity (t)
Seed production by different agencies	3,000
Seed production by Seed Village Program	2,700
Punjab Agricultural University seed farms	15
Pulses Section, Punjab Agricultural University	20
Progressive farmers	130
Private agencies	120
Total	5,985

Source: Bains et al. 2006.

Table 17. Seed production of SML668, rainy season 2003

Agency	Quantity (t)
Punjab Agricultural University seed farms	45
PUNSEED (Punjab State Seed Corporation)	58.2
Private agencies	500
Progressive farmers	300
Pulses Section, Punjab Agricultural University	20
National Science Council	40
Total	963.2

Source: Bains et al. 2006.

Table A18. Area of SML668 planted at Punjab Agricultural University farms, summer 2004

Name of the farm	Area planted (ha)
University seed farm, Naraingarh	12
Regional research station, Gurdaspur	0.8
University seed farm, Ladhowal	16
University seed farm, Faridkot	12
Total	40.8

Source: Bains et al. 2006.

Table A19. Area under mungbean in Punjab, 1995-2004

Year/Session	Area (ha)	
	Rainy	Summer
1995-96	52,600	n.a.
2000-01	23,000	n.a.
2002-03	65,000	25,000
2003-04	n.a.	40,000

n.a. = not available

Source: Punjab Agricultural University; Bains et al. 2006.

Table A20. Nucleus/basic seed production of SML668 in India, 2000-04

Year/session	No. of progenies grown	No. of progenies selected	Seed produced (kg)
Summer 2000	350	260	80
Rainy 2001	352	310	40
Summer 2002	310	233	100
Rainy 2002	260	212	68
Summer 2003	504	456	102
Rainy 2003	481	425	150
Summer 2004	552	-	-

Source: Bains et al. 2006.

Table A21. Amount of seed of various improved varieties produced in Bangladesh, 2002

Variety	Total amount of seed produced and distributed (t)	
	2002	2003
BARIMUNG 5 (NM 92)	870	4,200
BARIMUNG 2	2,645	5,915
BINA MUNG 5	310	830
BINA MUNG 2	160	450
BU mug 1 [VC 6372(45-8-1)]	8	82
BU mug 2 [VC 6370(30-65)]	300	61
Total	3,993	11,538

Source: Afzal et al. 2006.

REFERENCES

Abrol, I. P., K. F. Bronson, J. M. Duxbury, and R. K. Gupta. 1997. Long-term soil fertility experiments with rice-wheat rotation in South Asia. In *Long-term soil fertility experiments with rice-wheat rotation in South Asia,* Rice-Wheat Consortium Paper Series 1, ed. I. P. Abrol, K. F. Bronson, J. M. Duxbury, and R. K. Gupta. New Delhi: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Afzal, M. A., M. M. Haque, and S. Shanmugasundaram. 2004. Random amplified polymorphic DNA (RAPD) analysis of selected mungbean [*Vigna radiata* (L.) Wilczek] cultivars. *Asian Journal of Plant Sciences* 3 (1): 20–24.

Afzal, M. A., M. A. Bakr, A. Hamid, M. M. Haque, and M. S. Aktar. 2006. Adoption and seed production mechanisms of modern varieties of mungbean in Bangladesh. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia, DFID Mungbean Project for 2002–2004*. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Ali, M., I. A. Malik, H. M. Sahir, and A. Bashir. 1997. *The mungbean green revolution in Pakistan.* Technical Bulletin No. 24. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Amirthaveni, S., and R.Y. Yang. 1998. *High-iron mungbean recipes from South Asia*. AVRDC Publication No. 98-480. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Amiruzzaman, M., and M. Shahjahan. 2006. Country report for Bangladesh. In *Processing and utilization of legumes,* ed. S. Shanmugasundaram. Tokyo, Japan: Asian Productivity Organization.

Anderson, J. R. 1997. On grappling with the impact of agricultural research. A background paper for a presentation to the International Centers' Week (ICW), Washington, D.C. An earlier version, "On measuring the impact of natural resources research" prepared for the Advisor's Conference, Department for International Development (DFID), formerly the Overseas Development Administration (ODA), Sparsholt, U.K., July 9, 1997, in proceedings circulated on diskette.

AVRDC (The World Vegetable Center). 1976. *AVRDC mungbean report 1975*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 1977. *AVRDC progress report 1976*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 1981. *AVRDC progress report 1979*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 1988. *AVRDC Progress report 1986*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 1998. *AVRDC report 1997*. AVRDC Publication No. 98-481. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 1998b. *Proceedings of international consultation workshop on mungbean, September 7–11, 1997, New Delhi, India*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 2000. *AVRDC report 1999*. AVRDC Publication No. 00-503. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 2006. AVRDC mungbean project report (year two, April 2006–September 2006): Popularization of extra short duration mungbean cultivars for poverty alleviation and improved nutrition in Bihar, Rajasthan and Jharkhand, India, Based on Punjab model. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Bahl, P. N. 1999. *The union of Myanmar: Report of the consultancy mission on grain legume production*. Bangkok, Thailand: Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific (FAO/RAPA).

Bains, K., R. Aggarwal, and L. Barakoti. 2006. Development and impact of iron-rich mungbean recipes. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, ed. S. Shanmugasundaram. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Bains, K., R.Y. Yang, and S. Shanmugasundaram. 2003. *High-iron mungbean recipes for North India.* AVRDC Publication 03-562. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Bains, T. S., J. S. Brar, G. Singh, H. S. Sekhon, and B. S. Kumar. 2006. Status of production and distribution of mungbean seed in different cropping systems. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, ed. S. Shanmugasundaram. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Borlaug, N. E. 1973. Building a protein revolution on grain legumes. In *Nutritional improvement of food legumes by breeding*, ed. M. Milner. Rome: Protein Advisory Group of the United Nations.

Catipon, E. M., B. M. Legaspi, and F. A. Jarilla. 1988. Development of mungbean varieties from AVRDC lines for the Philippines. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B. T. McLean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Chainuvati, C., N. Potan, and T. Worasan. 1988. Mungbean and blackgram production and development in Thailand. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B.T. McLean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Chen, H. M. 2007. Development of molecular markers for bruchid and mungbean yellow mosaic virus resistance in mungbean. PhD thesis, National Ching-Hsing University, Taiwan.

Chen, H. M., C. A. Liu, C. G. Kuo, C. M. Chien, H. C. Sun, C. C. Huang, Y. C. Lin, and H. M. Ku. 2007. Development of molecular markers for a bruchid (*Callosobruchus chinenesis*, L.) resistance gene in mungbean. *Euphytica* 157: 113–122.

Cheng, X. Z. 1993. Research and utilization of AVRDC mungbean lines in China. In *The study and application of AVRDC mungbean in China*, ed. X. Z. Cheng, Y. T. Wang, and C. Y. Yang. Bangkok, Thailand: Asian Regional Center, AVRDC (ARC/AVRDC).

________. 1996. *Mungbean*. Beijing: China Agricultural Press.

Cheng, X. Z., and L. F. Lin. 1993. High yielding cultivation technique for mungbean. In *The study and application of AVRDC mungbean in China*, ed. X. Z. Cheng, Y. T. Wang, and C. Y. Yang. Bangkok, Thailand: ARC/AVRDC.

Erskine, W., and S. Nesbitt. 2009. How can agricultural research make a difference in countries emerging from conflict. *Experimental Agriculture* 45: 313–321.

ESCAP (United Nations Economic and Social Commission for Asia and the Pacific). 1985. Economic and social survey of Asia and the Pacific. Bangkok, Thailand: ESCAP.

Evenson, R. E., and D. Gollin. 2003. Assessing the impact of the green revolution, 1960 to 2000. *Science* 300: 758–762.

FAO (Food and Agriculture Organization of the United Nations). 1985. T*he state of food and agriculture*. Rome: FAO.

Fernandez, G. C. J., and S. Shanmugasundaram. 1988. The AVRDC Mungbean Improvement Program: The past, present, and future. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B. T. McLean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Fletcher, A. M. 1993. *The AVRDC story. Twenty years of service to tropical agriculture.* AVRDC Publication No. 93–406. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Gopalan, C., B. V. Rama Sastri, C. V. Balasubramnaian, B. S. Narasinga Rao, Y. G. Deosthale, and K. C. Pant. 1989. *Nutritive value of Indian foods*. Hyderabad, India: Indian Council of Medical Research.

Green, S. K., and D. H. Kim, eds. 1992. Mungbean yellow mosaic disease. In *Proceedings of the second international mungbean symposium*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Grover, D. K., K. Weinberger, and S. Shanmugasundaram. 2002. Status paper on mungbean production, consumption, and marketing in India: Special focus on Punjab state. Paper presented at the DFID Mungbean Project for 2002–2004 planning meeting, ICRISAT, Hyderabad, India, May 23–25.

________. 2003. *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 2006. Socio-economic impact of new short duration mungbean varieties in Punjab. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, ed. S. Shanmugasundaram. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Haque, M. M., A. Hamid, M. A. Afzal, M. A. Bakr, M. A. Rahman, A. N. Mondal, M. J. Ali, and A. Z. Sarker. 2006. Development of short duration mungbean cultivars for cereal-based cropping systems in Bangladesh. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, ed. S. Shanmugasundaram. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Hobbs, P., and R. Morris. 1996. *Meeting South Asia's food requirements from rice-wheat cropping systems: Priority issues facing researchers in the post green revolution era*. Natural Resources Group Paper 96/01. Mexico: International Maize and Wheat Improvement Center (CIMMYT).

Huijie, Z., N. H. Li, X. Z. Cheng, and K. Weinberger. 2003. *The impact of mungbean research in China*. AVRDC Publication No. 03-550, Working Paper No.14. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

IPB (Institute of Plant Breeding). 1978. *IPB annual report 1976–78*. Philippines: IPB and College of Agriculture, University of the Philippines at Los Baños.

Institute of Crop Germplasm Resources. 1993. *Compilation of papers on technology and utilization of AVRDC improved mungbeans in China*. Beijing: Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences, Department of Science and Technology, Ministry of Agriculture, and AVRDC Asian Regional Center, China Agricultural Press.

________. 1999. *Proceedings on technology and utilization of mungbean in China*. China: Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences, Department of Science and Technology, Ministry of Agriculture, and AVRDC Asian Regional Center, China Agricultural Press.

Jansen, H. G. P., and S. Charnnarongkul. 1992. *Economic analysis of AVRDC mandate crops through baseline surveys:Mungbean in Thailand*. AVRDC Working Paper No. 6. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Jat, M. L., K. Raj, O. E. Gupta, and R. Ortiz. 2006. Diversifying the intensive cereal cropping systems of the Indo-Ganges through horticulture. *Chronica Horticultrae* 46 (3): 16–20.

Khanal, N., D. Harris, L. T. Sherpa, R. K. Giri, and K. D. Joshi. 2006. *Testing promotion of mungbean in cereal fallows in the low hills and* terai *agroecosystem of Nepal*. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, ed. S. Shanmugasundaram. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Lantican, R. M., and R. S. Navarro. 1988. Breeding improved mungbeans for the Philippines. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B. T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Lin, L. F., and X. Z. Cheng. 1988. Introduction and utilization of AVRDC mungbean in China. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B.T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

MacKenzie, D. R., and S. Shanmugasundaram. 1973. The AVRDC grain legume improvement programme. In *Proceedings of the first IITA grain legume improvement workshop*. Ibadan, Nigeria: International Institute of Tropical Agriculture.

Malik, I. A., Y. Ali, and M. Saleem. 1988. Incorporation of tolerance to mungbean yellow mosaic virus from local germplasm into exotic large seeded mungbean. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B.T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Maneepun, S. 2006. Traditional processing and utilization of legumes. In *Processing and utilization of legumes*, ed. S. Shanmugasundaram. Tokyo, Japan: Asian Productivity Organization.

Meelu, O. P., and R. A. Morris. 1988. Green manure management in rice-based cropping systems. In *Sustainable agriculture*: *Green manure in rice farming*. Laguna, Philippines: International Rice Research Institute.

Morton, F., R. E. Smith, and J. M. Poehlman. 1982. *The mungbean*. Mayaguez: University of Puerto Rico.

Muthiah, A. R. 2006. Opportunities for the cultivation of extra short duration mungbean in Tamil Nadu, India. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, ed. S. Shanmugasundaram . AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Pandey, R. K., W. T. Herrera, and A. N. Villegas. 1988. Drought response of mungbean genotypes under a sprinkler irrigation gradient system. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B.T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Pannu, R. K., and D. P. Singh. 1988. Influence of water deficits on morpho-physiological and yield behavior of mungbean *Vigna radiata* (L.) Wilczek. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B.T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Paroda, R. S. 1995. Production of pulse crops in Asia: Present scenario and future options. In *Production of pulse crops in Asia,* ed. S. K. Sinha and R. S. Paroda. FAO/RAPA Publication No. 1995/8. Bangkok, Thailand: FAO/RAPA.

Pingali, P., and M. Shah. 1999. Rice-wheat cropping systems and the Indo-Gangetic Plains: Policy re-directions for sustainable resource use. In *Sustaining rice-wheat production systems: Socio-economic policy issues*, ed. P. Pingali. Rice-Wheat Consortium Paper Series 5. New Delhi, India: Rice-wheat Consortium for Indo-Gangetic Plains.

Pookpakdi, A. 1991. On-farm research and transfer of technology in mungbean production for northeastern farmers: A case study conducted by Kasetsart University. In *Proceedings of the mungbean meeting 1990*, ed. C. Thavarasook. Bangkok, Thailand: Tropical Agricultural Research Center.

Sekhon, H. S., G. Singh, S. Poonam, and S. Pushp. 2006. Agronomic management of mungbean grown under different environments. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, AVRDC Publication No. 06-682, S. ed. S. Shanmugasundaram. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Sekhon, H. S., T. S. Bains, B. S. Kooner, and P. Sharma. 2007. Grow summer mungbean for improving crop sustainability, farm income, and malnutrition. *Acta Horticulturae* 752: 459–464.

Shanmugasundaram, S. 1988. *A catalog of mungbean cultivars released around the world*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________. 2001. New breakthrough with mungbean. *Centerpoint* 19 (2): 1–2.

________. 2003. Present situation and economic importance of legumes in Asia and Pacific region. In *Processing and utilization of legumes,* ed. S. Shanmugasundaram. Tokyo, Japan: Asian Productivity Organization.

________, ed. 1998. *International consultation workshop: Proceedings of the mungbean workshop*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________, ed. 2004. *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia, DFID Mungbean Project for 2002–2004*. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

________, ed. 2006. *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia, DFID Mungbean Project for 2002–2004.* Proceedings of the final workshop and planning meeting, Punjab Agricultural University, Ludhiana, Punjab, India, May 27–31 2004. AVRDC Publication No. 06-682. 342. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Shanmugasundaram, S., and D. H. Kim. 1996. Mungbean. In *Genetics, cytogenetics, and breeding of crop plants,* vol. 1. *Pulses and oilseeds,* ed. P. N. Bahl and P. M. Salimath. New Delhi, India: Oxford and IBH Publishing Co.

Shanmugasundaram, S., and A.T. Tschanz. 1987. Breeding for mungbean and soybean disease resistance. In *Varietal improvement of upland crops for rice-based cropping systems*. Laguna, Philippines: International Rice Research Institute, Los Baños.

Shanmugasundaram, S, G. Singh, and H. S. Sekhon. 2004. Role of mungbean in Asian farming systems and relevance of coordinated research and development programs in Asia. In *Role of legumes in crop diversification and poverty reduction in Asia*, ed. C. L. L. Gowda and S. Pande. Patancheru, India: ICRISAT.

Siag, R. K., and V. Prakash. 2006. Scope of mungbean (*Vigna radiata* (L.) Wilczek) in Rajasthan (India) technology and extension gaps in productivity. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, ed. S. Shanmugasundaram. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Singh, J. 2006. Country report for India (1). In *Processing and utilization of legumes,* ed. S. Shanmugasundaram. Tokyo, Japan: Asian Productivity Organization.

Singh, R. B. 1988. Trends and prospects for mungbean production in South and Southeast Asia. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B.T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Srinives, P. 1998. Collaborative mungbean breeding research between AVRDC and its southeast Asia partners with emphasis on Thailand. In *Proceedings of the international consultation workshop on mungbean*, ed. S. Shanmugasundaram. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Thirumaran, A. S., and M. A. Seralathan. 1988. Utilization of mungbean. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B. T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Tickoo, J. L., and A. Satyanarayana. 1998. Progress in mungbean breeding research with special emphasis on disease and insect resistance, constraints and future directions. In *Proceedings of the international consultation workshop on mungbean*, ed. S. Shanmugasundaram. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Tickoo, J. L., C. S. Ahn, H. K. Chen, and S. Shanmugasundaram. 1988. Utilization of the genetic variability from AVRDC mungbean germplasm. In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram and B. T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Timsina, J., and D. J. Connor. 2001. Productivity and management of rice-wheat cropping systems: Issues and challenges. *Field Crops Research* 69: 93–132.

Vijayalakshmi, P. S., S. Amirthaveni, R. P. Devada, K. Weinberger, S. C. S. Tsou, and S. Shanmugasundaram. 2003. *Enhanced bioavailability of iron from mungbean and its effects on health of school children*. Technical Bulletin No. 20. AVRDC Publication 03-559. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Wallis, E. S., and D. E. Byth. 1988. Food legumes: "Slow runners forever?" In *Proceedings of the second international mungbean symposium*, ed. S. Shanmugasundaram, and B. T. McClean. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Weinberger, K. 2003a. Impact analysis of mungbean research in South and Southeast Asia. Final report of GTZ Project. The World Vegetable Center (AVRDC), Shanhua, Taiwan.

________. 2003b. The impact of iron bio-availability-enhanced diets on the health and productivity of school children: Evidence from a mungbean feeding trial in Tamil Nadu, India. In *International conference on impacts of agricultural research and development: Why has impact assessment research not made more of a difference?*, ed. D. J. Watson. Mexico: International Center for Maize and Wheat Improvement (CIMMYT).

Weinberger, K., M. R. Karim, and M. N. Islam. 2006. Economics of mungbean cultivation in Bangladesh. In *Improving income and nutrition by incorporating mungbean in cereal fallows in the Indo-Gangetic Plains of South Asia*, ed. S. Shanmugasundaram. AVRDC Publication No. 06-682. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Yang, R.S., and S. C. S. Tsou. 1998. Mungbean as a potential iron source in South Asian diets. In *Proceedings of international consultation workshop on mungbean*. Shanhua, Taiwan: The World Vegetable Center (AVRDC).

Zhang, H. Y., and Z. H. Wang. 1991. High-yielding cultivation of Zhong Lu #1 in the red loam region of Hunan. In *Compilation of papers on technology and utilization of AVRDC improved mungbeans in China*. Bangkok, Thailand: ARC/AVRDC.

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