# การศึกษาขนาดของเมล็ดและการถ่ายทอดลักษณะขนาดของเมล็ดถั่วเขียว

**นางสาว พรรณธิภา ณ เชียงใหม่**

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# THE STUDY OF SEED SIZE AND ITS INHERITANCE IN MUNGBEAN

**Miss Pantipa Na Chiangmai**

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# THE STUDY OF SEED SIZE AND ITS INHERITANCE IN MUNGBEAN

Suranaree University of Technology has approved this thesis submitted in partial fulfillments for the Degree of Doctor of Philosophy

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ขนาดเมล็ดเป็นองค์ประกอบผลผลิตที่สำคัญของถั่ว การศึกษาอิทธิพลของขนาดเมล็ดที่มีต่อลักษณะต่างๆของถั่วเขียว รวมทั้งการศึกษาลักษณะการถ่ายทอดของขนาดเมล็ดสามารถใช้เป็นข้อมูลในการปรับปรุงพันธุ์ถั่วเขียว วัตถุประสงค์ในการศึกษา เพื่อศึกษาอิทธิพลของขนาดเมล็ดที่มีต่อลักษณะต่าง ๆ ของถั่วเขียวที่ปลูกในฤดูฝน อิทธิพลที่มีต่อการงอกของเมล็ด อิทธิพลที่มีต่อความสามารถในการต้านทานแมลง และอิทธิพลที่มีต่อการทำถั่วงอก โดยใช้พันธุ์/สายพันธุ์ ทั้งหมดเจ็ดพันธุ์/สายพันธุ์ที่ได้ทำการแยกเมล็ดเป็นสองขนาดคือขนาดใหญ่และเล็กโดยใช้ตะแกรง วางแผนการทดลองแบบ split plot ให้พันธุ์เป็น main plot และขนาดเมล็ดเป็น subplot ผลการศึกษาพบว่า ต้นที่ปลูกจากเมล็ดใหญ่มีเมล็ดที่มีขนาดใหญ่กว่าต้นที่ปลูกจากเมล็ดเล็ก นอกจากนี้ พบว่าเมล็ดขนาดใหญ่มีเปอร์เซ็นต์การงอกสูงกว่าเมล็ดขนาดเล็กหลังการเก็บรักษา ไม่พบความแตกต่างในการต้านทานต่อแมลงของเมล็ดทั้งสองขนาดแต่พบว่าถั่วงอกที่เพาะจากเมล็ดขนาดใหญ่จะมีขนาดใหญ่กว่าที่เพาะจากเมล็ดเล็ก

สำหรับการศึกษาการถ่ายทอดลักษณะขนาดของเมล็ดได้จากการสร้างลูกผสมแบบพบกันหมดครึ่งชุดโดยใช้พ่อแม่ทั้งหมดหกพันธุ์ (สายพันธุ์) ทำการศึกษาจากสองประชากร ได้แก่ ลูกผสมชั่วที่หนึ่ง ($F_1$) และลูกผสมชั่วที่สอง ($F_2$) จากการศึกษาพบว่าพันธุ์ที่มีเมล็ดขนาดใหญ่มีความสามารถในการรวมตัวทั่วไป (GCA) เป็นบวกและพันธุ์ที่มีเมล็ดขนาดเล็กให้ค่าเป็นลบ พบความหลากหลายในการแสดงความสามารถในการรวมตัวเฉพาะ (SCA) ในลักษณะผลผลิตและองค์ประกอบผลผลิต การคาดคะเนจากค่าความแปรปรวนทางพันธุกรรมและความสามารถในการรวมตัวอย่างแคบ พบว่า ขนาดเมล็ด ความยาวฝัก จำนวนเมล็ดต่อฝักและความสูงมีการแสดงออกของยีนแบบบวก ขณะที่น้ำหนักสดและน้ำหนักแห้งมีการแสดงออกของยีนแบบข่ม และจากการศึกษาค่าสหสัมพันธ์ทั้งแบบ phenotypic และ genotypic พบว่า ขนาดเมล็ดเป็นลักษณะที่ทดแทนกับลักษณะองค์ประกอบผลผลิตอื่นๆ เช่น จำนวนเมล็ดต่อฝัก ทำให้ไม่พบอิทธิพลของขนาดเมล็ดต่อลักษณะผลผลิต

สาขาวิชาเทคโนโลยีการผลิตพืช ลายมือชื่อนักศึกษา.....พรรณธิกา ณ เชียงใหม่.....

ปีการศึกษา 2547 ลายมือชื่ออาจารย์ที่ปรึกษา..........

PANTIPA NA CHIANGMAI : THE STUDY OF SEED SIZE AND ITS INHERITANCE IN MUNGBEAN. THESIS ADVISOR : PROF. AREE WARANYUWAT, Ph.D. 103 PP. ISBN 974-533-298-4

Seed size is an important yield component of mungbean. The studies were to evaluate the effect of seed size on some characters and the inheritance of seed size character which could be informative for mungbean improvement. The purposes of this study were to determine the effect of seed size on agronomic characters in the rainy season, seed germination, weevil resistance and the efficiency of sprout production. Seeds of seven varieties/lines of mungbean were classified into two sizes, large and small by using mesh. The experiment was conducted in a split-plot design using varieties/lines as the main plot, seed sizes as the subplot. The results of field study showed no difference of seed size on agronomic characters studied but the seeds of plants grown from large seeds tended to be larger than those from small seeds. It was also found that large seeds had higher percent seed germination than small seeds after storage. There was no difference in weevil resistance between two seed sizes. Mungbean sprouts from large seeds were bigger than from small seeds.

The study on the inheritance of seed size was conducted in half-diallel crosses which employed six parents. The studied populations were first generation ($F_1$) and second generation ($F_2$) offsprings. The result showed that the large-seeded varieties had positive GCA effect for increasing seed size while the small-seeded varieties showed negative GCA. Variable SCA effects were found for yield and most of the yield component traits. The estimates of genetic variance and narrow sense heritability revealed that seed size, pod length, number of seeds per pod and plant height were important for additive gene action while biomass and total dry matter showed dominance gene action. The study on phenotypic and genotypic correlation indicated that seed size was compensated with other yield components such as the number of seeds per pod which resulted in nonsignificant yield difference between large and small seed sizes.

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Academic Year 2004 Advisor's Signature Aree Waranyuwat

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Pantipa Na Chiangmai

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# CHAPTER I

# General Introduction

## General background of mungbean

Mungbean [*Vigna radiata* L. Wilczek] is a leguminous species grown widely in South Asia. It is called mung, moong, green gram in India and mungo in the Phillippines. Mungbean is an important source of human protein and adapts well to the tropical environments. The production of mungbean is adversely affected by many factors such as low genetic potential of existing varieties, environmental stresses, diseases and insect pests and poor cultural practices.

India, Burma, Thailand and Indonesia produce almost 90 percent of the world production. The seeds are mainly sprouted and consumed cooked or raw. They may also be split, boiled, roasted or ground into flour to make a variety of desserts, snacks and main dishes. Moreover, mungbean contains several minerals such as potassium, sodium, magnesium, phosphorus, iron and calcium and vitamins A, B1, B2, C and niacin. However, it is not a perfect protein source and should be consumed with other sources of protein which have high percentage of sulphur-containing amino acids, such as cereals and sesame.

Mungbean is grown widely because of its short duration which can be harvested in 70-75 days after planting. It is grown over a broad range of soil fertility and moisture conditions and with varying level of cultural practices and technology. It is also suitable for use in multiple cropping systems.

In the 2002/2003 crop year, Thailand was estimated to sow approximately 2 million rai with the expected production of 257,928 metric tons or an average yield of 838 kg/ha (DOA, Thailand [on-line]).

The Asian Vegetable Research and Development Center (AVRDC) was organized in 1972 in the Republic of China (Taiwan) with financial support from Asian countries. Mungbean was chosen as one of the crops on which to conduct research and remarkable breeding progress has been made since then. Since the founding of AVRDC in 1972 up to 1993, more than 6,000 Vigna crosses (VC) had been developed (Laosuwan, 1999; Srinives *et al*., 2001).

AVRDC had improved many mungbean lines, many of which had been named and released, or used as parents in mungbean breeding program of different countries. Examples of such varieties are NURI (Indonesia), PUSA-105 (India), Nm-51 (Pakistan), PSU1 (Thailand) and Er Lu No. 2 (China) (AVRDC, 2000).

## Mungbean Breeding in Thailand

In Thailand, the Department of Agriculture (DOA) is responsible for national mungbean research in all aspects. The main center for mungbean research is located at Chai Nat Field Crops Research Center (CFCR), Chai Nat. The major objectives of the breeding program at this center are to develop stable and high-yielding varieties and to improve cultivars for resistance to pests and diseases.

Mungbean breeding in Thailand was started in 1969 with yield trial of local and introduced cultivars or lines including an outstanding line M7A introduced from the Phillippines and selected by pure line selection in Thailand. This line was released as a variety U-thong 1. Prior to the release of PSU1 (parentage as VC2768 A) the breeding line was introduced from AVRDC and pure line selection in Thailand.

Moreover, two standard varieties which have been widely grown are Kamphaeng Saen 1 and 2. These varieties were selected from VC1973A and VC2778 A, repectively, by Kasetsart University, Kamphaeng Saen campus (Srinives, 1990).

## Research Objectives

1. To study the effect of seed size on some characters.
2. To study the inheritance of seed size.

# CHAPTER II

# Effect of seed size on some characters

## Abstract

Seed size is an important yield component of mungbean [*Vigna radiata* (L.) Wilczek]. This study was to determine the effect of seed size on some characters under the field and laboratory tests. Large and small seeds of seven varieties were used for field study in the rainy season of 2003. For laboratory study, five varieties were evaluated in a split-plot design with three replications on seed germination and sprout studies, while weevil resistance was evaluated in six varieties with four replications. The results of field study revealed no difference of seed size on the speed of emergence, days to first flowering, days to first pod maturity, plant height, biomass and total dry matter. Although varieties were different in seed yield and some yield components (e.g. 100-seed weight and pods per plant), seeds of different sizes of the same variety did not have effect on yield as well as other yield components. Nevertheless, the seeds of the plant grown from large seed tended to be larger than that from small seed. Moreover, it was found that large seeds had higher percent seed germination than small seeds. There were no difference in the number of eggs layed, the number of adult weevils and percent seed damage between two seed sizes. However, in SUT1 there seemed to be more resistant to weevil in the large seed as compared to small seed. In general, mungbean sprouts from large seeds were

heavier in weight, bigger in head and stem but were shorter than the sprouts from small seeds.

# Introduction

## Effect of seed size on some characters

Mungbean possesses high variability in seed size. Many varieties from India produce very small seed size approximately two to three grams per one hundred seeds, while other varieties of the AVRDC produce as a big seed size as eight grams per one hundred seeds. The study on seed size has been reported in many crops but that in mungbean is scarce.

Seed size has effects on many characters both in the field and laboratory tests. Seed emergence percentage and speed of emergence are the first characters that could be observed in the field which indicate the seed vigor. These characters usually differ under field stresses such as low temperature, wet or crusted soil in which small seeds of soybean and common bean perform better than large seeds due to seedlings from small seeds are less damaged than those from large seeds (Hoy and Gamble, 1987; Sexton *et al*., 1994). While in the field with no stress, mungbean and winter wheat of large seed size tend to do better in germination than small seed size (Chastain *et al*., 1995; Amin, 1999). These reports explained that larger endosperm enhanced emergence ability and larger cotyledons had higher photosynthetic rates and also produced larger hypocotyl (Black, 1956; Burris *et al*., 1971). Besides seed size, seeding depth and density also had effect on emergence and speed of emergence (Lafond and Baker, 1986; Tinius *et al*., 1991).

Amin (1999) reported that days to 50% pod maturity of large-seeded mungbean were earlier than those of small-seeded type. However, seed size had less effect on plant height than other characters. Nevertheless, Singh *et al*. (1972) reported that large seeds of soybean had greater supply of stored energy to support early seedling growth and consequently the plant stature. But seed size has been considered to be a significant factor only during the early stage of plant growth. This may be due to small seed has higher photosynthetic rate than large seed in soybean (Burris *et al*., 1971). Plants grown from small seeds of spring wheat were found emerging faster and accumulating less shoot dry weight than plants grown from large seeds (Lafond and Baker, 1986).

Although not all reports demonstrated the effects of seed size on yield, small seeds of several crop species had little influence on final yield (LeRoy *et al*., 1991b; Tinius *et al*., 1991; Main and Nafziger, 1994). However, small seed size was associated not only with increased yield but also with increased over-all growth except maturity in common bean (White *et al*., 1992) and it emerged faster than large seed in wheat (Lafond and Baker, 1986). Small-seeded genotypes are probably physiologically most efficient, especially at warmer sites and higher latitudes (White *et al*., 1992).

An alternative explanation that seed size had influence on growth and yield was its correlation with cell size in the seed and in the rest of the plant and the cell size may have an important influence on these characters in barley (White and Gonzalez, 1990). Smaller cell size of the small seed cultivars presumably concentrates the cellular machinery and thus confers some physiological advantage such as greater phytosynthetic rates which result in greater yield than large seed size in some study. Moreover, small cell size has been associated with increased specific leaf nitrogen and greater rate of photosythesis as found in wheat (Morgan *et al*.,

1990) and with increased sucrose concentration in roots of sugar beet (Doney *et al*., 1981). However, the effect of seed size on yield is associated with planting site. As in common bean in the warm climate, the small seed had many characters such as seed growth rate, mean partitioning and yield higher than large seed; but at the cool site, the seed size did not differ in many characters (Sexton *et al*., 1994).

One observation on the effect of seed size was the indirect effect of seed number on yield which showed a strong yield component compensation between seed number and seed size (Spaeth and Sinclair, 1984; Board *et al*., 1999). The component compensation may be the reason of why there were no effects of seed size on yield in soybean (Hoy and Gamble, 1987; Singh *et al*., 1972), mungbean (Amin, 1999) and common bean (Perin *et al*., 2002 [on-line]). The correlation between yield and yield component with seed size has been estimated in different varieties and crop plants. Not all reports presented the same conclusions on the correlation between seed size and yield. Much research not only showed high correlation of large seed size with yield, larger-seeded pods also produced heavier seeds than small-seeded pods (Ries, 1971; Amin, 1999).

Many reports showed low genetic correlation between yield and seed size of soybean which ranged from –0.27 to 0.02 (Anad and Torrie, 1963) and -0.59 to 0.22 (Kwon and Torrie, 1964), 0.43 to 0.66 in $F_3$ lines (Johnson *et al*., 1955) and –0.07 to 0.27 for $F_6$ and $F_7$ generations (Byth *et al*., 1969a,b). Simpson and Wilcox (1983) reported low phenotypic correlation in soybean (0 to 0.21). However, the reasons for low correlation between seed size and yield were unclear. For other characters that had high phenotypic correlation with seed weight was pod width with the value of 0.63 on a plant basis and of 0.84 on a plot-mean basis (LeRoy *et al*., 1991a).

Moreover, selection for seed weight was more effective by using pod width than direct selection for seed weight *per se* (Bravo *et al*., 1980). Indirect selection could be done early in 20 days after pollination in soybean in which the pod reached its maximum width while the maximum seed weight was obtained in 45 days after pollination.

### Effects of seed size on quality

In greenhouse and field studies with green beans (*Phaseolus vulgaris* L.), seed size and protein content were confounded in the expression of seedling growth and bean yield, but when the effect of seed size was statistically removed, yield was related to protein content (Ries, 1971). The larger and higher protein seeds not only produced larger seedlings, but seedlings also had a much higher protein content for next season. The seedling weight and protein content were both highly correlated with both seed weight (larger and small seed) and protein content because of high correlation of mg protein per seed with seed weight. However, seedling size, yield and number of fruit were more highly correlated with protein per seed than with seed size (Ries, 1971). The larger seed had higher levels of protein (mg protein/g) than the smaller seeds although the variation between lines was considerable. However, the larger seed did not result in proportionally larger seedlings for all cultivars, as indicated by the significant interaction of cultivars with seed size (Ries and Everson, 1973). Seed size may be of primary important effect to protein content because larger seeds have more protein. Large seeds not only have more total protein on a weight basis, but they have a higher percent protein (mg per g) in every comparison made. The results agreed with wheat and oats that indicated the importance of seed size and quality, expressed as total protein (Ries, 1971; Ries and Everson, 1973).

## Effects of seed size on stored insects

Callosobruchus seed weevils (*Callosobruchus maculatus* F., *C. chinensis* F., and *Callosobruchus* spp. Coleoptera) or bruchids, are destructive storage pests of certain grain legumes in the tropics. They are present in all tropical and subtropical climates and attack a wide range of grain legume species, including mungbean and blackgram (Southgate, 1978; Taleker, 1988).

There was little information on the study of the effect of pest on seed size of mungbean. The reports of wild varieties with small seeds were found to be damaged less by bruchids than accessions with large seeds (Jakhmola and Singh, 1971). Moreover, Epino and Morallo-Rejesus (1983) reported that *C. chinensis* preferred hard, large and heavy seeds for oviposition. Khattak *et al*. (1987) evaluated the effect of seed size of mungbean accessions on the *C. maculatus* progenies, adult lifespan and development period. Progenies of *C. maculatus* feeding on mungbean accessions with small grain size were smaller than progenies feeding on large-seeded accessions. However, some later reports showed that seed size had no significant effect on disease and insect incidence in mungbean (Amin, 1999). Taleker and Lin (1992) also reported that seed size was not involved in resistance. By using the same seed size, they found that counterfeit seeds made from resistant line of mungbean had less damage from cowpea weevil than that from susceptible line. However, Taleker and Lin (1988) showed the factors involving the resistance of mungbean to cowpea weevil were texture layer and seed size.

# Materials and Methods

## 1. Classify the seed sizes

Seven varieties/lines of mungbean were used in the study (Table 1). All varieties/lines (from now on will refer to as varieties) were classified into two sizes, large and small, by using the screen of mesh. The round holes of mesh No. 20 is 3.175 mm in diameter (mesh screen of the Seed Buro Equipment Company, Chicago. IL, USA). Seeds that could not pass through mesh No. 20 were classed as large size and that passed through No. 20 were classed as small. After the sizes of seeds were classified, each variety (Table 1) was weighed for 100 seeds for 3 times and the average was taken as 100-seed weight (Table 2). These different seed sizes were used for testing both in the field and laboratory.

## 2. Study the effect of seed size on yield and other characters in the field.

Two seed sizes of 7 varieties were tested in the field to evaluate the effect of seed size on different characters. The experiment was conducted in the rainy season, using a split plot in RCB design with 3 replications. Main plots were varieties and subplots were seed sizes. Each subplot consisted of 4 rows, spaced 50 cm between rows and 20 cm between hills with 2 plants/hill. Each row was 5 m long. The data were collected on the speed of emergence, height, biomass, total dry matter, days to first flowering and days to first pod maturity. Plant height, biomass and total dry matter were recorded at the same stage. Yield components of individual plants were recorded as number of pods/plant, number of seeds/pod, number of seeds/plant, and

100-seed weight. The procedure for data collection was similar to the method described by Chaiteing (2002).

**Table 1. Name and pedigree of varieties/lines used in the experiment.**

| Variety/line[1] | Sources |
|---|---|
| SUT1 | U-thong 1 x VC1560 D |
| SUT2 | VC3689 A x KPS1 (Backcross to KPS1) |
| SUT3 | KPS2 x VC3689 A (BC to KPS2) |
| SUT4 | VC3689 A x PSU1 (BC to PSU1) |
| PSU1 | Selected from Line VC2768 A obtained from AVRDC |
| KPS2 | Selected from Line VC2778 A obtained from AVRDC |
| CN36 | Pagasa 1 x PHLV 18 (AVRDC) |
| CN60 | MG50-10A (Y) x ML-6 (AVRDC) |
| VC3751A | AVRDC |
| VC3781A | AVRDC |
| V4718 | AVRDC |

[1] SUT1-4 = Suranaree University of Technology 1-4

KPS = Kamphaeng Saen

CN = Chai Nat

**Table 2. The 100-seed weight of two sizes of mungbean varieties/lines.**

| Variety/Line | Small seed group (g/100 seeds) | Large seed group (g/100 seeds) |
|---|---|---|
| SUT1 | 5.77 | 7.55 |
| SUT2 | 5.64 | 7.08 |
| SUT3 | 5.47 | 7.09 |
| SUT4 | 5.41 | 6.73 |
| PSU1 | 5.37 | 7.19 |
| CN36 | 5.63 | 7.00 |
| CN60 | 5.51 | 7.33 |
| VC3751A | 5.22 | 6.43 |
| KPS2 | 5.26 | 7.17 |
| VC3781A | 5.09 | 6.54 |

## 3. Field performance

Field performance was evaluated in the 2003 rainy season on the Suranaree University of Technology farm (SUT farm), Nakhon Rathasima. In each planting, 100 seeds from each seed class (large and small) of seven varieties were weighed before seeding and this weight would be used in comparison with the seeds of new crop. The experiment was conducted in a randomized complete block in a split-plot design with three replications. Each plot consisted of four 5-meter rows spaced 50 cm apart. Two seeds per hill were planted at a distance of 20 cm between hills. Plots were kept weed-free throughout the season by haloxyfop-R-methyl ester (Gallant super) spray as well as hand weeding. Fungicides and insecticides were applied as needed.

## 4. Data collection

### 4.1 The speed of emergence

All four rows were determined for the speed of emergence. The total number of seedlings emerged were counted several times during the emergence period until the maximum emergence percentage was reached. Seedlings with both cotyledons elevated above the soil surface were considered complete emergence. The total number of emerged seedlings in the last count was taken as the final emergence percentage. Values from all emergence counts were used to determine the emergence rapidity index which was referred to as coefficient of emergence (CE), which was derived from the coefficient of velocity of germination as proposed by Kotowski (1926 referred by Hoy and Gamble, 1987), and is expressed as:

$$\mathrm{CE} = \frac{100\,(E_1 + E_2 + \ldots + E_X)}{E_1D_1 + E_2D_2 + \ldots + E_XD_X},$$

where $\mathrm{E_X}$ is the total number of emerged seedlings multiplied by days after planting, and $Dx$ is the number of days from planting to the *x th* count.

In this study, the speed of emergence was recorded twice daily in the morning (8.00 hr) and evening (16.00 hr).

### 4.2 Character measurement

Yield and yield component characters such as the number of pods per plant, number of seeds per plant, number of seeds per pod, 100-seed weight and length of pod were recorded at harvest. The length of pod and number of seeds per pod were measured from the same pod. Twenty pods taken at random were measured for pod length and number of seeds per pod. Data analysis was based on the plot means. The yield per plant and 100-seed weight were based on 12% moisture content by using Dole Model 400 B Moisture tester.

1. Yield.

The formula for calculating yield per hectare was

$$Y = \frac{\text{yield/plot (g)} \times 10{,}000\ (\text{m}^2) \times 100 - X}{1{,}000\ \text{g} \times \text{harvested area } (\text{m}^2) \times 100 - 12}$$

where, Y = yield (kg/hectare)

X = the seed moisture content before adjustment (%)

**2. 100-seed weight = mean of 3 samples randomly taken from each plot.**

3. Plant height (cm) measured from the cotyledonary node to the tip of the plant.

4. The average number of pods per plant counted on ten randomly selected plants.

5. Pod length (cm) was measured from 20 pods by random selection.

6. Number of seeds per pod was measured from the same sample of pod length determination.

### 4.3 Pre-emergence herbicide application and cultural practices

On the same day of planting, alachlor was sprayed at rate of 3.125 liters/hectare immediately after planting. After emergence, the seedlings were thinned to desired stand density and the fertilizer N-P-K (12-24-12) at rate of 312.5 kg/hectare was side-dressed and covered by hand. Pesticides were sprayed about 30 days after planting for 3-4 times until flowering.

## 5. Standard germination test

Five varieties (KPS2, CN36, CN60, PSU1 and VC3751A) were used in the study of the effect of seed size on seed germination which was tested twice in the laboratory using between-paper method. The first test was made after seed size classification before storage (0 month storage). After which the seeds of different sizes were stored at room temperature and in a cold room. The second set of seeds were kept for 4 months to compare the effect of seed size after storage in different conditions. Each germination test was done 3 times (replications) with 100 seeds per replication. The rolls of seeds were incubated in illumination chamber with the light intensity of 2,200 lux at 20 $^{o}$C/30 $^{o}$C and kept for 16 hr in the dark and 8 hr in light. After one week, germinating seeds were counted in each roll and presented as percent seed germination.

## 6. Study on the effect of seed size on weevil resistance.

To study the damage by weevil, seeds of six mungbean varieties/lines (SUT1, CN36, PSU1, CN72, KPS1 and VC3781A) were seperated into two sizes. Five grams of each size of each variety were placed in a plastic box. The one-day old age of adult weevils (*Callosobruchus chinensis*) used in this study were prepared as follow. In laboratory, adult weevils were collected from mungbean storage and cultured on clean mungbean seeds in plastic boxes. One week later, the eggs were laid on the seed surface and then the adult weevils were removed from the old plastic boxes to new plastic boxes filled with clean seeds. Continued culture the collected eggs for two to three weeks until the adult weevils hatched. At one-day old after the hatch, the adult weevils were collected and used for the weevil resistance study. The experimental design was a split plot in RCB with 4 replications. Main plots were varieties and subplots were seed sizes. Each treatment was done by release of 10 couples (10 females and 10 males) of adult weevils in a plastic box containing two sizes of the seed separated in two compartments. All seeds were weighed for initial weight. After rearing the weevils for seven days, the weevils were removed from the plastic box and left only eggs that were laid on the seed surface and the numbers of eggs were counted. Continued culturing eggs for two weeks until the new weevils hatched. The number of emerged weevils was counted and the final seed weights were recorded. Similar seed samples without weevils were used as control. The final weight of control seed was used for damaged seed calculation.

$$\text{Damaged seed weight (\%)} \quad = \quad \frac{\text{Initial weight (g)} - \text{Final weight (g)}}{\text{Initial weight (g)}} \quad \times \ 100\ \%$$

### 7. Study on the efficiency of sprout production.

In each seed size group, the seeds were weighed out 100 grams. They were filled in a plastic basket and covered with nylon net and damp cloth overtop. The water was then filled into the basket to reach the cloth and left for 5-10 minutes, then the water was decanted off and the basket kept in the dark. This process was routinely done three times a day (morning, afternoon and evening). After three days the bean sprouts were weighed and the sprout production efficiency could be estimated.

# Results and Discussion

## 1. Field study on the effect of seed size on yield and other characters.

### The speed of emergence

The speed of seed emergence was determined and analyzed as shown in Table 3. All varieties used in this study showed no difference in the speed of seed emergence. Large and small seeds had the same emergence speed in the field (Table 4).

Although not much information available on the speed of seed emergence of different seed sizes in mungbean as well as other crops, some reports showed the effect of seed size on seed germination. Kaufmann (1967); Abdullahi and Vanderlip (1972) found that large seed tended to perform better in germination, seedling growth and vigorous seedling than those of small seeds. However, some research in barley and soybean found no difference in seed emergence of different seed sizes (Demirlicakmak *et al,* 1963; Tekrony *et al.*, 1987). Lafond and Baker (1986) found that small seed emerged faster than large seed in barley. Abulhahi and Vanderlip (1972) reported the interaction between seed source and seed size that affected seedling establishment in the field. The speed of emergence was reported depending on seedling depth and density (Lafound and Baker, 1986; Tinius *et al*., 1991).

Table 3. Mean squares of twelve characters of mungbean grown in the 2003 rainy season.

| Source | df | Speed of emergence | $1^{st}$ day flowering | $1^{st}$ pod maturing | Plant height | Biomass | TDM | Pod length | 100-seed weight | Pods/ plant | Seeds/ pod | Seeds/ plant | Yield (kg/ ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Varieties/Lines | 6 | 0.02ns | 4.54ns | 4.98** | 126.84ns | 166.22ns | 14.99ns | 0.55ns | 1.10** | 53.87* | 4.40ns | 973.8ns | 280,299.16* |
| Error (a) | 12 | 0.02 | 1.78 | 0.17 | 66.38 | 592.57 | 24.73 | 0.43 | 0.10 | 16.40 | 2.62 | 884.2 | 93,299.64 |
| Seed sizes | 1 | 0.001ns | 0.38ns | 0.10ns | 29.17ns | 70.28ns | 1.10ns | 0.05ns | 0.24ns | 4.47ns | 0.34ns | 196.3ns | 19,120.64ns |
| V/L x sizes | 6 | 0.02ns | 0.83ns | 0.10ns | 66.9* | 484.88ns | 22.96* | 0.25ns | 0.02ns | 10.33ns | 0.48ns | 432.5ns | 67,860.70ns |
| Error (b) | 14 | 0.01 | 0.48 | 0.10 | 18.80 | 198.71 | 8.00 | 0.53 | 0.06 | 4.31 | 1.27 | 369.8 | 45,521.04 |
| CV (a) (%) | | 0.6 | 4.0 | 0.8 | 13.5 | 30.8 | 27.3 | 7.1 | 4.9 | 21.5 | 16.0 | 21.9 | 22.7 |
| CV (b) (%) | | 0.5 | 2.1 | 0.6 | 7.2 | 17.9 | 15.5 | 7.8 | 4.0 | 11.1 | 11.1 | 14.1 | 15.9 |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

TDM = Total dry matter.

Table 4. Means of characters as affected by seed size in the 2003 rainy season.

| | Coefficient of emergence (%) | | | 1st Flowering (day) | | | 1st Pod maturing (day) | | | Plant height (cm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety/Line | Small | Large | Mean | Small | Large | Mean | Small | Large | Mean | Small | Large | Mean | Difference |
| SUT1 | 21.95 | 21.99 | 21.97 | 34.3 | 33.7 | 34.0 | 52.0 | 52.0 | 52.0a | 55.7 | 54.3 | 55.0 | 1.3ns |
| SUT2 | 22.10 | 22.10 | 22.10 | 32.3 | 33.0 | 32.7 | 50.0 | 50.0 | 50.0c | 74.1 | 59.8 | 67.0 | 14.3** |
| PSU1 | 22.14 | 22.00 | 22.07 | 33.3 | 33.3 | 33.3 | 51.0 | 50.3 | 50.7b | 57.7 | 51.9 | 54.8 | 5.7ns |
| CN36 | 22.16 | 22.15 | 22.16 | 34.3 | 34.3 | 34.3 | 52.0 | 52.0 | 52.0a | 57.3 | 62.8 | 60.1 | -5.5ns |
| CN60 | 21.89 | 22.17 | 22.03 | 32.3 | 31.7 | 32.0 | 50.0 | 50.0 | 50.0c | 64.0 | 63.6 | 63.8 | 0.4ns |
| VC3781A | 22.08 | 22.02 | 22.05 | 33.0 | 31.7 | 32.3 | 50.3 | 50.3 | 50.3bc | 61.3 | 65.3 | 63.3 | -4.1ns |
| KPS2 | 22.06 | 22.14 | 22.10 | 32.3 | 33.0 | 32.7 | 50.0 | 50.0 | 50.0c | 58.3 | 58.9 | 58.6 | -0.6ns |
| Mean | 22.05 | 22.08 | 22.07 | 33.1 | 33.0 | 33.0 | 50.8 | 50.7 | 50.7 | 61.2 | 59.5 | 60.4 | 1.7 |

In column, means followed by a common letter are not significantly different at the 5% level by DMRT.

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

Table 4. continued.

| Variety/Lines | Biomass per plant (g) | | | Total dry matter per plant (g) | | | | Pod length (cm) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Small | Large | Mean | Small | Large | Mean | Difference | Small | Large | Mean |
| SUT1 | 68.61 | 91.32 | 79.96 | 15.73 | 19.31 | 17.52 | -3.58ns | 9.34 | 9.10 | 9.22 |
| SUT2 | 100.62 | 66.50 | 83.56 | 22.90 | 15.38 | 19.14 | 7.52** | 8.83 | 9.06 | 8.94 |
| PSU1 | 81.96 | 85.32 | 83.64 | 18.16 | 17.37 | 17.77 | 0.79ns | 9.60 | 9.32 | 9.46 |
| CN36 | 63.44 | 78.61 | 71.03 | 15.42 | 18.33 | 16.88 | -2.90ns | 9.68 | 8.95 | 9.32 |
| CN60 | 82.56 | 82.19 | 82.38 | 21.15 | 20.57 | 20.86 | 0.57ns | 9.49 | 9.86 | 9.67 |
| VC3781A | 77.15 | 82.84 | 79.99 | 17.31 | 20.87 | 19.09 | -3.56ns | 8.88 | 8.66 | 8.77 |
| KPS2 | 69.31 | 74.98 | 72.14 | 15.68 | 16.80 | 16.24 | -1.11ns | 9.13 | 9.51 | 9.32 |
| Mean | 77.66 | 88.25 | 82.96 | 18.05 | 18.37 | 18.21 | -0.32 | 9.28 | 9.21 | 9.24 |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

Table 4. continued.

| Variety/Lines | 100-seed weight (g) | | | Pods/plant (no.) | | | Seeds/pod (no.) | | | Seeds/plant (no.) | | | Yield (kg/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Small | Large | Mean | Small | Large | Mean | Small | Large | Mean | Small | Large | Mean | Small | Large | Mean |
| SUT1 | 6.71 | 6.95 | 6.83a | 22.2 | 21.7 | 22.0ab | 9.0 | 8.4 | 8.7 | 135.9 | 129.3 | 132.6 | 1,623.6 | 1,513.2 | 1,568.4ab |
| SUT2 | 5.78 | 5.84 | 5.81de | 24.9 | 19.4 | 22.2a | 9.3 | 10.0 | 9.7 | 160.0 | 144.7 | 152.4 | 1,836.8 | 1,428.2 | 1,632.5a |
| PSU1 | 6.23 | 6.25 | 6.24c | 17.8 | 15.9 | 16.9abc | 10.2 | 9.9 | 10.1 | 146.7 | 129.3 | 138.0 | 1,313.0 | 1,183.3 | 1,248.2abc |
| CN36 | 6.34 | 6.46 | 6.40bc | 13.4 | 16.5 | 15.0c | 11.6 | 10.6 | 11.1 | 105.1 | 137.7 | 121.4 | 1,120.1 | 1,401.7 | 1,260.9abc |
| CN60 | 6.59 | 6.81 | 6.70ab | 17.6 | 17.9 | 17.7abc | 9.8 | 10.2 | 10.0 | 132.5 | 124.8 | 128.6 | 1,075.2 | 1,034.1 | 1,054.6c |
| VC3781A | 5.59 | 5.62 | 5.60e | 21.8 | 21.1 | 21.5ab | 11.3 | 11.0 | 11.1 | 155.6 | 151.5 | 153.6 | 1,462.5 | 1,493.0 | 1,477.8ab |
| KPS2 | 5.85 | 6.21 | 6.03cd | 16.1 | 16.7 | 16.4bc | 10.4 | 10.3 | 10.3 | 131.1 | 119.4 | 125.3 | 1,134.2 | 1,213.3 | 1,173.7bc |
| Mean | 6.16 | 6.31 | 6.24 | 19.1 | 18.5 | 18.8 | 10.2 | 10.0 | 10.1 | 138.1 | 133.8 | 135.9 | 1,366.5 | 1,323.8 | 1,345.2 |

In column, means followed by a common letter are not significantly different at the 5% level by DMRT.

### Days to first flowering

Table 3 showed the effect of neither varieties nor seed size on the number of days to first flowering in rainy season. CN60 was earliest which began to flower in 32 days after planting, while CN36 and SUT1 were latest, flowering in approximately 34 days. However, days to first flowering of all varieties were not different (Table 4). This result was in agreement with that of Amin (1999) who found in the study of mungbean cropping system that seed size had no effect on days to flowering. The effect of seed size was dependent on location and season. This study occurred in rainy season under good cultural condition, therefore the seed of different sizes germinated at the same speed which resulted in plants of the same age.

### Days to first pod maturing

Table 3 showed highly significant difference among varieties in the number of days to first pod maturity. CN36 and SUT1 were later maturing than others (Table 4). It should be noted that these two varieties were also the latest in days to first flowering. Seed size had no effect on maturity.

This result was in agreement with Amin (1999) who reported that the first and 50 % pod maturity varied among varieties. This result indicates that maturity character is genotype dependent rather than the effect of seed size.

### Plant height, biomass and total dry matter

Three characters, e.g. plant height, biomass and total dry matter were determined from the same samples at R6 stage. Plant height was not affected by seed size or varieties/lines but significant interaction between varieties/lines and seed size was observed on plant height as shown in Table 3. SUT2 was the only variety that showed different plant heights. Plants from small seeds were taller than plants derived from large seeds (74.13 and 59.80 cm, repectively) as shown in Table 4. However, in soybean the large seeds gave taller plant than did the small seeds (Singh *et al*., 1972; Burris *et al*., 1973; El-Zahab and Zahran, 1976; Tekrony *et al*., 1987). But Amin (1999) reported in mungbean that seed size did not influence plant height. These contradicting results could be that seed size might have influence during the early stage of plant growth (Singh *et al*., 1972). Burris *et al*. (1971) and White *et at*. (1992) also reported that soybean plants derived from small seeds had higher physiological activity such as greater photosynthetic rate and specific leaf nitrogen than plants from large seeds (Morgan *et al*., 1990).

Although biomass production of all varieties/lines was not affected by seed size (Table 3), plants from large seeds tended to show higher plant weight than plants from small seeds, except SUT2 (Table 4). Small-seed SUT2 produced more biomass than plants from large seeds. However, SUT2 had wider difference between two seed sizes but the nonsignificant interaction effect could be due to the large variation as indicated by high coefficient of variation (Table 3).

This finding was in agreement with that of Burris *et al*. (1971). Perin *et al*. (2002) also reported that large seed contributed greater weight of both shoot and root than small seed in common bean at early vegetative stage.

Total dry matter (TDM) was a trait that closely correlated with biomass because these two characters were determined from the same plant samples, and high variation was also observed. Neither varieties nor seed size had influence on TDM, but significant interaction between these two characters was observed (Table 3). This interaction could be signified by variety SUT2 in which the plants from small seeds produced more TDM than the plants derived from large seeds (Table 4).

### Yield and yield components

Pod length and number of seeds per pod were not affected by seed size. All varieties had the same pod length and number of seeds per pod, ranging between 8.66 to 9.86 cm and 8.4 to 11.6 seeds, respectively (Table 4). Similar result was also reported by Amin (1999).

Number of seeds per plant of all varieties/lines studied were not different (Table 3 and 4), ranging from 121.1 in CN36 to 153.6 seeds in VC3781A. The only two significantly different characters were 100-seed weight and number of pods per plant (Table 3). These two yield components may have contributed to the difference in seed yield of the varieties studied. The difference in seed weight was due entirely to varieties because the analysis of seed size did not show variation in seed weight. VC3781A had smallest seed (5.60 g/100 seeds) and SUT1 and CN60 had largest seed (6.70 and 6.83 g/100 seeds, respectively). These results indicated that both small and large seeds had no influence on 100-seed weight of each variety. Demirlicakmak *et al*. (1963) also reported no effect of seed size on the 100-kernel weight in barley.

Number of pods per plant varied among all varieties. This trait was also due entirely to mungbean genotype because the variance due to seed size on this character was not significant (Table 3). SUT1, SUT2, VC3781A, CN60 and PSU1 produced more pods per plant than KPS2 and CN36 (Table 4).

The analysis of variance in Table 3 showed that yield of plants from different seed sizes was not different. However, varieties significantly differed in seed yield, indicating the importance of the genetic make up of a variety that contributed to final yield as found in this study. CN60 and KPS2 were the only varieties that gave lower yields than the rest, although not significantly different from some varieties (Table 4). SUT2 gave highest yield of 1,632.5 kg/hectare eventhough not significantly different from other high yielders (Table 3).

Many reports showed that yield was highest for large seeds and lowest for small seeds in varieties and tests in soybean and barley (Demirlicakmak *et al*., 1963; Singh *et al*., 1972; El-Zahab and Zahran, 1976; Tekrony *et al*., 1987). Although large seeds can anticipate the growth of bean crop, plants originating from small seeds may compensate their slower initial growth providing a similar grain yield (Perin *et al*., 2002). Many reports found no correlation between seed weight and yield (Astin and Longden, 1964; Singh *et al*., 1972; Johnson and Luedders, 1974; Hoy and Gamble, 1987; Amin, 1999; Perin *et al*., 2002).

## 2. Studies on seed germination

The analysis and mean values of the germination test of the seed at 0 month (before storage) and 4 months after storage in different conditions are presented in Table 5 and Table 6, respectively. At 0 month the seeds of both sizes showed no difference in germination. However, differences were found among varieties. Interaction effect between variety and seed size was also observed. CN36, KPS2, VC3751A and CN60 showed highest percentage of seed germination (96.33 %, 95.5 % 94 %, and 93 %, respectively) while the lowest was PSU1 (87%) (Table 6).

**Table 5. Analysis of variance of seed germination percentage at 0 and 4 months of storage in two conditions.**

| | | | 4 months | |
|---|---|---|---|---|
| Source | df | 0 month | Cold room | Room temperature |
| Varieties/lines | 4 | 81.33* | 359.87** | 1087.37** |
| Error (a) | 8 | 17.18 | 24.14 | 17.97 |
| Seed size | 1 | 36.30ns | 192.53** | 240.83** |
| V/L x Size | 4 | 52.47* | 38.20* | 87.67** |
| Error (b) | 10 | 11.23 | 7.07 | 9.80 |
| CV (a) (%) | | 4.4 | 5.4 | 5.0 |
| CV (b) (%) | | 3.6 | 2.9 | 3.7 |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.
ns = nonsignificant

After 4 months of storage in two conditions, all varieties showed differences in germination (Table 5). Seed size also had effect on germination. However, only CN60 and PSU1 showed differences at all storage conditions. Large seeds always germinated better than small seeds irrespective of keeping conditions. Nevertheless, the other three varieties when kept in the same condition showed no difference in germination (Table 6). It must be noted also that varieties were different in seed germination, particularly the small seeds of PSU1 that had fairly low germination percentage even when kept in a cold room for 4 months. It seemed that CN36 and VC3751A retained exceptionally high germination at all storage conditions, while CN60 had very poor seed quality when kept at room temperature even only for 4 months.

Table 6. Means of seed germination percentage at 0 and 4 months of storage in two conditions.

| | | | | | 4 months | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 month | | | | Room temperature (RT) | | | | Cold room (CR) | | | |
| Variety/line | Large | Small | Mean | Difference | Large | Small | Mean | Difference | Large | Small | Mean | Difference |
| KPS2 | 97.33 | 93.67 | 95.50ab | 3.67ns | 89.67 | 89.67 | 89.67ab | 0.00ns | 91.67 | 88.67 | 90.17abc | 3.00ns |
| CN36 | 94.67 | 98.00 | 96.33a | -3.33ns | 97.33 | 94.67 | 96.00ab | 2.67ns | 97.67 | 94.67 | 96.17ab | 3.00ns |
| CN60 | 96.67 | 89.33 | 93.00abc | 7.33* | 75.33 | 59.33 | 67.33c | 16.00** | 95.33 | 90.33 | 92.83abc | 5.00* |
| PSU1 | 91.00 | 83.00 | 87.00c | 8.00* | 80.00 | 68.67 | 74.33c | 11.33** | 84.67 | 71.00 | 77.83d | 13.67** |
| VC3751A | 91.67 | 96.33 | 94.00abc | -4.67ns | 96.67 | 98.33 | 97.50a | -1.67ns | 97.33 | 96.67 | 97.00a | 0.70ns |
| Mean | 94.27a | 92.07b | 93.17 | 2.20 | 87.80a | 82.13b | 84.97 | 5.67 | 93.33a | 88.27b | 90.80 | 2.53 |

In column, means followed by a common letter are not significantly different at the 5% level by DMRT.

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

### 3. Studies on weevil resistance

The evaluation for bruchid resistance was expressed in ovipositional preference which was measured by number of eggs laid on both small and large seeds of six varieties. The analysis for number of emergence and damaged seed weight was shown in Table 7. The result showed that neither seed sizes nor varieties had the effect on oviposition; however, interaction between seed size and variety was observed. There were slightly more eggs (229.0) on small seed than on large seeds (223.0) (Table 8). Only SUT1 showed significantly more eggs laid on small seeds (264.5) than those on large seeds (211.5).

Table 7 indicated that the number of adult weevils and damaged seed weight (recorded two weeks after the egg count) on both seed sizes within each variety were the same, but there were differences in the weevil numbers and damaged seed weight (%) among varieties. Since seed size had no effect on the number of eggs laid, the number of adult weevils hatched and damaged seed, but significant interactions were observed in all characters which indicated that the varieties were important factor. SUT1 and VC3781A had the highest number of weevils and CN72 had the lowest, however, the latter was one of the varieties that contained the highest number of eggs laid on the seed (Table 8). This response could be due to the weevil resistance of CN72 as previously claimed, thus the number of hatched weevils were lowest among all varieties with 16.9 weevils per five grams of seeds as compared to 61.5 weevils on SUT1 seeds. The result illustrated the antibiosis phenomena of CN72 to the development of the weevils when damaged seed weight (%) was taken into consideration. All varieties were similar, varying from 16.52% in KPS1 to 22.05% in VC3781A. It was also noted that CN72 was examined three days after all other varieties, therefore damaged seed weight (%) could be overestimated (18.75%). Seed damage weight (%) of this variety should have been less since there were much less weevils feeding on the seeds than other varieties.

From the study of seed size on weevil resistance, it appeared that the size of seeds did not have influence on resistance except the variety SUT1 that showed decreasing effect of small seeds in all respects. Similar response of some other varieties was also observed but not statistically and significantly different.

**Table 7. Mean quare of three characters involving the damage seed weight (%) by weevils in mungbean.**

| | | Mean square | | |
|---|---|---|---|---|
| Source | df | No. of eggs | No. of weevils | Damaged seed weight |
| Varieties/Lines | 5 | 1,940.98ns | 2,734.74** | 34.41ns |
| Error (a) | 15 | 2,216.21 | 178.48 | 15.62 |
| Seed sizes | 1 | 432.00ns | 25.52ns | 6.31ns |
| Varieties x Sizes | 5 | 1,721.00* | 334.27* | 20.91** |
| Error (b) | 18 | 538.78 | 90.76 | 2.39 |
| CV (a) (%) | | 20.8 | 34.6 | 20.7 |
| CV (b) (%) | | 10.3 | 24.7 | 8.1 |

*, ** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant

.

Table 8. Average number of eggs, number of weevils and seed damage weight (%) of six mungbean varieties.

| | No. of eggs | | | | No. of weevils | | | | Damage (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety/line | Large | Small | Mean ± sd | Difference | Large | Small | Mean ± sd | Difference | Large | Small | Mean ± sd | Difference |
| SUT1 | 211.5 | 264.5 | 238.0 ± 69.5 | -53.0** | 50.5 | 72.5 | 61.5 ± 11.7a | -22.0** | 17.25 | 22.95 | 20.10 ± 4.3 | -5.70** |
| CN36 | 216.5 | 202.2 | 209.4 ± 5.1 | 14.2ns | 37.5 | 41.0 | 39.2 ± 13.7b | -3.5ns | 16.90 | 17.25 | 17.08 ± 1.4 | -0.35ns |
| CN72 | 242.8 | 253.0 | 247.9 ± 23.3 | -10.2ns | 19.0 | 14.8 | 16.9 ± 10.6c | 4.2ns | 18.15 | 19.35 | 18.75 ± 2.5 | -1.20ns |
| PSU1 | 245.2 | 219.5 | 232.4 ± 16.8 | 25.8ns | 28.2 | 32.5 | 30.4 ± 15.3b | -4.2ns | 21.05 | 19.10 | 20.08 ± 2.1 | 1.95ns |
| KPS1 | 202.5 | 227.0 | 214.8 ± 36.5 | -24.5ns | 23.5 | 24.5 | 24.0 ± 7.2b | -1.0ns | 15.30 | 17.75 | 16.52 ± 3.6 | -2.45ns |
| VC3781A | 219.8 | 208.0 | 213.9 ± 18.2 | 11.8ns | 68.2 | 50.5 | 59.4 ± 13.9a | 17.8* | 23.75 | 20.35 | 22.05 ± 2.4 | 3.40ns |
| Mean± sd | 223.0<br>± 17.2 | 229.0<br>± 24.8 | 226.0 ± 23.2 | 6.0 | 37.8<br>± 18.6 | 39.3<br>± 20.4 | 38.6 ± 9.5 | -1.5 | 18.73<br>± 3.1 | 19.46<br>± 2.0 | 19.10 ± 1.5 | -0.73 |

In column, means followed by a common letter are not significantly different at the 5% level by DMRT.

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

### 4. Studies on the efficiency of sprout production.

Seed size and variety had highly significant effects on sprout production (Table 9). In addition, the size of the sprouts was also highly significantly different. No interaction between variety and seed size was observed on the size or the weight of the sprouts produced except stem diameter.

**Table 9. Means squares of four characters as affected by seed size on sprout production**

| Source | df | Seed weight | Head diameter | Stem diameter | Stem length |
|---|---|---|---|---|---|
| Varieties/Lines | 4 | 254.02** | 0.0033** | 0.0019** | 5.662** |
| Error (a) | 8 | 3.61 | 0.0003 | 0.0001 | 0.185 |
| Seed sizes | 1 | 365.54** | 0.0753** | 0.0056** | 1.221** |
| Varieties x Sizes | 4 | 4.92ns | 0.0005ns | 0.0002* | 0.069ns |
| Error (b) | 10 | 6.03 | 0.0004 | 0.00004 | 0.035 |
| CV (a) % |  | 5.1 | 3.3 | 3.1 | 10.1 |
| CV (b) % |  | 6.6 | 3.7 | 2.8 | 4.4 |

*, ** Significantly different at 0.05 and 0.01 levels of probability, respectively.
ns = nonsignificant

On average, SUT1 and SUT2 produced highest weight of sprouts (g/100 seeds) (Table 10). Large seeds always gave higher production than small seeds in all varieties. The same was true for the head diameter of sprouts. In all varieties, large seed size always gave larger sprout head than the small seeds. SUT1 with larger seed size than others produced larger sprout head. However, CN36 gave thicker stem than others but rather shorter than most varieties. It must be noted that CN60 was inferior to other varieties in all these characters. Stem length was the only character that showed a reverse effect of seed size where small seeds produced longer sprouts than large seeds. Therefore, it could be concluded that SUT1 and SUT2 were suitable for sprout production because they had highest weight of sprout.

Table 10. Means of four characters as affected by seed size on sprout production.

| | Weight (g/100 seeds) | | | Head diameter (mm) | | | Stem diameter (mm) | | | | Stem length (cm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety | Large | Small | Mean | Large | Small | Mean | Large | Small | Mean | Difference | Large | Small | Mean |
| SUT1 | 45.89 | 37.46 | 41.67ab | 6.29 | 5.25 | 5.77a | 2.46 | 2.17 | 2.32b | 0.29** | 4.82 | 4.86 | 4.84ab |
| SUT2 | 46.68 | 37.95 | 42.31a | 5.84 | 4.66 | 5.25bc | 2.44 | 2.17 | 2.30b | 0.26** | 5.05 | 5.63 | 5.34a |
| PSU1 | 39.53 | 34.50 | 37.02c | 5.82 | 4.66 | 5.24bc | 2.45 | 2.24 | 2.35b | 0.21** | 4.36 | 4.77 | 4.56b |
| CN36 | 43.28 | 35.63 | 39.46bc | 5.88 | 5.06 | 5.47b | 2.87 | 2.42 | 2.64a | 0.45** | 3.32 | 3.81 | 3.56c |
| CN60 | 28.86 | 23.80 | 26.33d | 5.62 | 4.89 | 5.21c | 2.24 | 2.09 | 2.16c | 0.15* | 2.71 | 3.21 | 2.96d |
| Mean | 40.85a | 33.87b | 39.36 | 5.89a | 4.89b | 5.39 | 2.49a | 2.12b | 2.31 | 0.37 | 4.05b | 4.46a | 4.26 |

In column, means followed by a common letter are not significantly different at the 5% level by DMRT.

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

# Conclusion

The size of mungbean seeds may have some association to yield and yield components and other agronomic characters including sprout production. Results of this study revealed that both the large and small seeds were not different in the speed of seedling emergence, days to first flowering, days to first pod maturity, plant height, biomass, and total dry matter production. It was also found in a given variety that seed size did not have effect on seed yield and yield component traits such as pod length, number of seeds per pod, number of pods per plant and 100-seed weight. Among all varieties studied, SUT1 gave the highest yield.

Three out of five varieties had the same seed germination percentage between large and small seeds, while the other two varieties (CN60 and PSU1) the larger seeds had higher germination at all keeping conditions. However, the latter two varieties appeared to quickly deteriorate germination capability especially when kept at room temperature even only for four months.

Large and small seeds showed no difference in weevil resistance because this was probably dependent on the genetic trait of a variety rather than the size of the seed, which CN72 appeared to be more resistant than others.

Large seeds could produce larger bean sprouts.

# References

Abdullahi, A., and Vanderlip, R. L. (1972). Relationships of vigor tests and seed source and size to sorghum seedling establishment. **Agron. J.** 64: 143-144.

Amin, Ad. M. Ul. (1999). Influence of seed size on the performance of mungbean varieties under postrice and upland cropping systems. Asia regional center-AVRDC [On-line serial].

**Available: http://www.arc-avrdc.org/pdf_files/Amin(17-N).pdf**

Anand, S. C., and Torrie, J. H. (1963). Heritability of yield and other traits and interrelationships among traits in the $F_3$ and $F_4$ generations of three soybean crosses. **Crop Sci.** 3: 508-511.

Austin, R. B., and Longden, P. C. (1964). Factors affecting seed performance**. Rep. 14, Natl. Phys. Lab.** 43-44.

AVRDC. (2000). Mungbean production [On-line]. Available:

**http://www.avrdc.org.tw/LC/mungbean/production/variety.html**

Black, J. N. (1956). The influence of seed size and depth of sowing on pre-emergence and early vegetative growth in subterranean clover (*Trifolium subterraneum* L.) **Aust. J. Agri. Res.** 7: 93-109.

Board, J. E., Kang, M. S., and Harville, B. G. (1999). Path analyses of the yield formation process for late-planted soybean. **Agron. J.** 91: 128-135.

Bravo, J. A., Fehr, W. R., and Rodriguez de Cianzio, S. (1980). Use of pod width for indirect selection of seed weight in soybeans. **Crop Sci.** 20: 507-510.

Burris, J. S., Wahab, A. H., and Edje, O. T. (1971). Effect of seed size on seedling performance in soybean. I. Seedling growth and respiration in the dark. **Crop Sci.** 11: 492-496.

Burris, J. S., Edje, O. T., and Wahab, A. H. (1973). Effects of seed size on seedling performance in soybean: II. Seedling growth and photosynthesis and field performance. **Crop Sci.** 13: 207-210.

Byth, D. E., Weber, C. R., and Caldwell, B. E. (1969a). Correlated truncation selection in soybeans. **Crop Sci.** 9: 699-702.

Byth, D. E., Caldwell, B. E., and Weber, C. R. (1969b). Specific and nonspecific index selection in soybeans. Glycine max (L.) Merrill. **Crop Sci.** 9: 702-705.

Chaitieng, Bubpa. (2002). **Inheritance of powdery mildew resistance in mungbean and development of molecular markers for marker-assisted selection.** Ph. D. Dissertation, Suranaree University of Technology, Thailand.

Chastain, T., Ward, G. K. J., and Wysocki, D. J. (1995). Stand establishment responses of soft white wheat to seedbed residue and seed size. **Crop Sci.** 35: 213-218.

Demirlicakmak, A., Kaufmann, M. L., and Johnson, L. P. V. (1963). The influence of seed size and seeding rate on yield and yield components of barley. **Can. J. Plant Sci.** 43: 330-337.

DOA, Thailand. (2002). Mungbean [On-line].
**Available: http://www.itdoa.com/doa _info/eco/jan46/jan_5.htm**

Doney, D. L., Wyse, R. E., and Theurer, J. C. (1981). The relationship between cell size, yield and sucrose concentration of the sugarbeet root. **Can. J. Plant Sci.** 61: 447-453.

El-Zahab, A., and Zahran, M. (1976). Effect of seed size on early growth, yield and yield contributing variables of soybean (*Glycine max* (L.) Merr.) **A. Acker Pflanzenbau** 143: 148-165.

Epino, P. B., and Morallo-Rejesus, B. (1983). Physico-chemical properties of mungbean (*Vigna radiata* (L.) Wilczek) seeds in relation to weevil resistance. **Philippines Entomologist** 6: 607-620.

Hoy, D. J., and Gamble, E. E. (1987). Field performance in soybean with seeds of differing size and density. **Crop Sci.** 27:121-126.

Jakhmola, S. S., and Singh, L. (1971). Relationship of seed size in green gram (*Phaseolus aureus* Roxb.) with the development and reproduction of pulse beetle (*Callosobruchus chinensis* Linn.). **JNKVV Res. J.** 5: 104-106.

Johnson, H. W., Robinson, H. F., and Comstock, R. E. (1955). Genotypic and phenotypic correlations in soybeans and their implications in soybean. **Agron. J.** 47: 477-483.

Johnson, D. R., and Luedders, V. D. (1974). Effect of planted seed size on emergence and yield of soybeans (*Glycine max* (L.) Merr.). **Agron. J.** 65: 117-118.

Khattak, S. U. K., Hamed, M., Khatoon, R., and Mohammad, T. (1987). Relative susceptibility of different mungbean varieties to *Callosobruchus maculatus* F. (Coleoptera: Bruchidae). **J. Stored Products Res.** 23: 139-142.

Kwon, S. H., and Torrie, J. H. (1964). Heritability of and interrelationships among traits of two soybean populations. **Crop Sci.** 4: 196-198.

Lafond, G. P., and Baker, R. J. (1986). Effect of genotype and seed size on speed of emergence and seedling vigor in nine spring wheat cultivars. **Crop Sci.** 26: 341-346.

Laosuwan, P. (1999). Mungbean varietal improvement: A review. **Songklanakarin J. Sci. Technol.** 30: 41-48.

LeRoy, A. R., Cianzio, S. R., and Fehr, W. R. (1991 a). Direct and indirect selection for small seed of soybean in temperate and tropical environments. **Crop Sci.** 31: 697-699.

LeRoy, A. R., Fehr, W. R., and Cianzio, S. R. (1991 b). Introgression of genes for small seed size from *Glycine soja* into *G. max*. **Crop Sci.** 31: 693-397.

Main, M. A. R., and Nafziger, E. D. (1994). Seed size and water potential effects on germination and seedling growth of winter wheat. **Crop Sci.** 34: 169-171.

Morgan, J. A., LeCain, D. R., and Wells, R. (1990). Semidwarfing genes concentrate photosynthetic machinery and effect leaf gas exchange of wheat. **Crop Sci.** 30: 602.608.

Perin, A., Araujo, A. P., and Teixeira, M. G. (2002). Effect of seed size on biomass and nutrient accumulation and on grain yield of common bean. **Pesq. Agropec. Bras.** 37 (12) (On-line serial).

Ries, S. K. (1971). The relationship of size and seed protein content of bean seed with growth and yield. **J. Amer. Soc. Hort. Sci.** 96: 557-560.

Ries, S. K., and Everson, E. H. (1973). Protein content and seed size relationships with seedling vigor of wheat cultivars. **Agron. J.** 65: 884-886.

Sexton, P. J., White, J. W., and Boote, K. J. (1994). Yield-determining processes in relation to cultivar seed size of common bean. **Crop Sci.** 34: 84-91.

Simpson, A. M., Jr., and Wilcox, J. R. (1983). Genetic and phenotypic associations of agronomic characteristics in four high protein soybean populations. **Crop Sci.** 23: 1077-1081.

Singh, J. N., Tripathi, S. K., and Negi, P. S. (1972). Note on the effect of seed size on germination, growth and yield of soybean (*Glycine max* (L.) Merr.). **Indian J. Agri. Sci.** 42 (1): 83-86.

Southgate, B. J. (1978). The importance of the Bruchidae as pests of grain legumes, their distribution and control. In S. R. Singh, H. F. Van Emden and T. A. Taylor (eds.). **Pests of Grain Legumes: Ecology and Control** (pp. 219-229)Academic Press, London.

Spaeth, S. C., and Sinclair, T.R. (1984). Soybean seed growth. II. Individual seed mass and component compensation. **Agron. J.** 76: 128-133.

Srinives, P. (1990). Mungbean breeding and genetic resources in Thailand. In **Proceeding of The Mungbean Meeting 90, February 23-24,** 1990. Chiang Mai, Thailand.

Srinives, P., Sorajjapinum W., and Koizumi, M. (2001). Mungbean breeding research at ARC-AVRDC/KU [On-line].

**Available: http://www.geocities.com/altanya55/Mung.htm**

Taleker, N. S. (1988). Biology, damage and control of bruchid pests of mungbean. pp. 329-342. *In* S. Shanmugasundaram and B.T. Mclean (eds.). Mungbean, **Proceeding of the Second International Symposium.** Asian Vegetable Research and Development Center, Shanhua, Taiwan, Replubic of China.

Taleker, N. S., Lin, C. P. (1992). Characterization of *Callosobruchus chinensis* (Coleoptera : Bruchidae) resistance in mungbean. **Entomol. Soc. Amer.** 85: 1150-1153.

Tekrony, D. M., Bustamam, T., Egli, D. B., and Pfeiffer, T. W. (1987). Effect of soybean seed size, vigor and maturity on crop performance in row and hill plots. **Crop Sci.** 27: 1040-1045.

Tinius, C. N., Burton, J. W., and Carter, T. E. Jr. (1991). Recurrent selection for seed size in soybean: I. Response to selection in replication populations. **Crop Sci.** 31: 1137-1141.

White, J. W., and Gonzalez, A. (1990). Characterization of the negative association between seed yield and seed size among genotypes of common bean. **Field Crop Res.** 23: 159-175.

White, J. W., Singh, S. P., Pino, C., Rios, M. J., and Buddenhagen, I. (1992). Effect of seed size and photoperiod response on crop growth and yield of common bean. **Field Crop Res.** 28:295-307.

# CHAPTER III

# Study on the inheritance of seed size

## Abstract

As seed size has effects on some mungbean characters, thus breeding for improving seed size has been a key objective of plant breeders. The objective of this research was to study the inheritance of seed size upon which the breeding program could be applied. Half diallel crosses were made employing six parents, two of which were large-seeded varieties (SUT1 and KPS1) and the other four were small-seeded (V3273, VC1173A, VC1210A and V4718). $F_1$ and $F_2$ populations were studied in 2003. The results showed that the large-seeded varieties had positive GCA effects for increasing seed size while the small-seeded lines showed negative GCA. SUT1 with highest GCA value was a good genetic source for increasing seed size. Either positive or negative GCA values were found for other yield components. SCA effects for seed size as well as most of other yield components were found in both $F_1$ and $F_2$ populations. Variable SCA effects were found for yield and most of the yield component traits. The highest heterosis for seed size in $F_1$ generation was observed in crosses V3273 x VC1210A and SUT1 x V3273, but that for various yield components varied depending on the crosses. The estimates of genetic variance and narrow sense heritability revealed that seed size, pod length, number of seeds per pod and plant height were important for additive gene action. Variation was found on the

number of pods per plant, number of seeds per plant and seed yield per plant in both the $F_1$ and $F_2$ generations. Biomass and total dry matter showed the dominance gene action. The study on phenotypic and genotypic correlation indicated that seed size was compensated with other yield components such as the number of seeds per pod which resulted in nonsignificant yield difference between large and small seed sizes.

# Introduction

## The inheritance of seed size

Seed size is an important yield component in legume species. It is inherited quantitatively. Many reports showed either positive phenotypic correlation of seed weight with seed yield (Singh *et al*., 1968; Gupta and Singh, 1969; Malik *et al*., 1982; Khan, 1985) or negative correlation (Malhotra *et al*, 1974) in *Phaseolus aureus* (Roxb.) (or currently *Vigna radiata*). However, Khan (1985) found significantly negative genotypic correlation (-0.935) but significantly positive correlation for phenotype (0.857).

Many studies showed that additive gene effect was predominant in the inheritance of seed weight (Bhargava *et al*., 1966; Singh and Jain, 1971; Wilson *et al*., 1985; Chung, 1997). However, significant specific combining ability (SCA) effects were reported in particular crosses by Singh and Jain (1971), Lal *et al*. (1982) and Wilson *et al*. (1985). Similar reports by Singh and Singh (1971), Rao *et al*. (1984) confirmed the presence of overdominance for seed weight. Imrie *et al*. (1985) reported the $F_1$ and $F_2$ generation means significantly lower than the midparent mean, indicating negative dominance of small seed size in mungbean. Malik *et al*. (1987) also reported that small seed size was partially dominant over large seed size with gene action predominantly additive. Transgressive segregation for small seed size was noted but the large seed size was not recovered in $F_2$ and subsequent generations.

## Heritability

Heritability ($h^2$) refers to the proportion of the phenotypic variance that is heritable and hence transmissible to the next generation. It may be expressed either as a fraction or a percent. Heritability estimates are utilized in estimating the gain, or genetic advance (*Gs*), that may be accomplished by one generation of selection from the mixed population being studied. Many experiments found seed size having high heritability and being higher than other yield companents (Bhargava *et al.*, 1966; Gupta and Singh, 1969; Singh and Malhotra, 1970; Ramana and Singh, 1987; Chung, 1997). As seed size is a quantitative character, therefore it is strongly influenced by environment due to seed size is changed following source-sink alteration applied during seed filling and the rate of seed growth was relatively constant across the early and late pods and it was affected only to a limited extent by the position of the seed in the pod (Egli, *et al.*, 1978). Moreover, heritability estimates for seed size vary depending on inheritance estimates used. For instance, broad-sense heritability estimates among the three crosses of soybean based on variance components were 35% on a plant basis, 52% on a plot basis and 89% on an entry-mean basis. Genetic gain averaged across environments of all crosses for seed weight was 6 mg/seed on a plant basis, 7 mg/seed on a plot basis and 8 mg/seed on an entry-mean basis (LeRoy *et al.*, 1991a).

## Heterosis

Heterosis has important implications in $F_1$ and for obtaining transgressive segregates in $F_2$ generation. Heterosis was calculated and could be compared with mid parent, better and top parent values for yield, yield components and other characters. The magnitude of heterosis provides a basis for determining genetic diversity and serves as a guide to the choice of desirable parent. The extent of heterosis could be varied bi-directionally according to crosses and characters and the hybrids which produced high heterotic effects usually could be a good source for developing the characters.

In grain legumes, the heterosis is generally due to dominance gene effects but also sometimes due to epistatic interaction. In self pollinated crops, it is possible to exploit such genetic manifestation only with a potentially workable sterility mechanism, if available. The information regarding epistatic interaction is useful in planning a breeding program for development of pure lines with enhanced yield potential.

In common with other heterosis experiments, in mungbean the spacing, environment and others are presumed to give an advantage or disadvantage to the hybrid plants. Midparent heterosis for seed weight was found both positive and negative values ranging from -4.48 to 8.35 % from many studies (Bhatnagar and Singh, 1964; Singh and Jain, 1970; Misra *et al*., 1970; Swindell and Poehlman, 1976; Reddy and Sreeramulu, 1982). Although more bold-seeded mungbean germplasm was utilized in hybridization to increase their seed size but negative heterosis for 1,000-seed weight was reported (Khattak *et al*., 2002a). The negative heterotic effect, therefore, could impare seed size improvement.

**Diallel cross**

Diallel cross consists of all possible crosses between a number of varieties. Reciprocal crosses, and the selfed parents, may or may not be omitted. Such a set of crosses is obviously of interest to the plant breeder, but the information obtained may not be worth the trouble of making the crosses.

The statistical analysis of a diallel cross has been described by Yates (1947 quoted in Gilbert, 1958). It consists of fitting additive main effects for parents, and their interactions in the individual crosses. Such a main effect is sometimes called general combining ability (GCA) or additive genetic component, while an interaction may be referred to as specific combining ability (SCA) or nonadditive genetic component. The GCA of each parent ($g_i$) should be examined when the objective is the development of superior genotypes while the SCA effects ($s_{ij}$) provides information about hybrid performance (Cruz and Regazzi, 1994 quoted in Franco *et al.*, 2001). According to Cruz and Vencovsky (1989 quoted in Franco *et al.*, 2001), the SCA of a parent with itself ($s_{ij}$) has great genetic significance and indicates the existence of unidirectional dominance. Negative $s_{ij}$ values indicate that deviations are predominantly positive, and vice-versa. The magnitude of $s_{ij}$ is indicative of varietal heterosis and their additive values express the mean values of such heterosis.

Therefore, this analysis allows broad inference on the nature of the gene effect for a characteristic under selection. Breeding programs can take advantage from this information to find the best selection strategy to transfer desirable traits between gene pools.

The interactions are part of the statistical description of the data, being the ups and downs which remain when the main effects have been taken out. The analysis is similar to that of factorial experiments, and merely assumes that the contributions of male and female parents are equally important. Moreover, the diallel mating design is extended to investigate the genetic parameters of reference populations. In Model II the parents of a diallel represent a random sample from a population in linkage equilibium, then a random effect model should be used in the analysis. Estimates of genetic variance component ($\sigma^2_A$ and $\sigma^2_D$) of Model II can be obtained, and inferences about the population from which the parents are selected can be made. However, two assumptions are necessary to estimate genetic variance components by Griffing's (1956) methods. The assumptions are that there is no epistasis and that genes are independently distributed in the parents. Griffing (1956) proposed four methods to analyze the combining ability.

Although the data for analysis in $F_1$ was very important in diallel cross studies for estimated gene action (Buerstmayr *et al*., 1999; Aher *et al*., 2001; Franco *et al*., 2001), it is difficult to obtain sufficient $F_1$ seeds for multiple location testing in self-pollinated crops where had emasculations must be made. So many researches reported later generation for estimated GCA and SCA analysis, $F_2$ and $F_3$ data were shown SCA can give better GCA estimates than the $F_1$ (Bhullar *et al*., 1979; Patil and Chopde, 1981). Jinks (1956) and Hayman (1957, 1958) compared diallel analysis of $F_1$ and $F_2$ analysis and found that both $F_1$ and $F_2$ were essentially the same. However, Cho and Scott (2000) used $F_2$ data in soybean, and Haussmann *et al*. (2001) used $F_2$ data in sorghum.

For legumes, many characters were determined from hybrids of the diallel cross method involving diverse mungbean genotypes (Khattak *et al*., 2002a). The results from the study of genetic basis of plant height at various growth stages and the degree of indetermination of plant height in mungbean through half-diallel cross showed that plant height at first flower was additively inherited. Both additive and dominant gene effects controlled the inheritance of plant height and degree of indetermination at many stages. However, the additive gene action was predominant as compared to dominant gene action for all the traits examined. For character showed high narrow and broad sense heritability could expected to response for the selection and development of mungbean genotypes as found minimum increase in plant height during post-flowering development (Khattak *et al*., 2002b).

Aher *et al*. (2001) studied yield contributing characters in mungbean by diallel analysis, excluding reciprocals and obtained $F_1$ hybrids from a 8 x 8 mating design. For many characters that were determined; day to flowering, day to maturity, plant height, length of pods, other yield component including 100-seed weight and grain yield per plant were found high significant GCA and SCA while additive gene effects were predominant. These results for gene action were similar to the study of Khattak *et al*. (2001) through a 6 x 6 diallel cross in mungbean that both additive and non-additive gene effects were found conditioning the inheritance of nodes of the first peduncle, clusters per plant, clusters on main stem and branches, pod per plant, 100-seed weight, grain yield per plant, biomass and harvest index. The additive gene action was found significant for nodes on main stem, average internodal length, branches per plant, pods per cluster, pod length and seed per pod. However, the predominance of additive genetic variance was observed in all traits.

As seed vigor and seed yield in soybean were significant for ability (GCA) effects and larger than specific combining ability (SCA) effects which indicated that level of seed vigor could be improved through breeding for high yield. Cho and Scott (2000) found both significant GCA and SCA effects which indicated that both additive and nonadditive genetic effects were involved in seed weight character.

# Materials and Methods

## 1. $F_1$ diallels

Six mungbean varieties/lines of different seed size were crossed in a half diallel resulting in 15 crosses [n(n-1)/2] as shown in Table 1. Agronomic characters of varieties/lines used in this study are presented in Appendix 1 and 2. The $F_1$ seeds were tested in a randomized complete block design with three replications to study the genetic effects of seed size, correlation and path coefficient between seed size and other characters. The experiment was conducted on the Suranaree University of Technology Experimental Farm (SUT farm) in the dry season of 2002. The soil type was Chatturat clay loam (Typic Haplustalts), containing 3.25% OM, 29 ppm $P_2O_5$, 300 ppm $K_2O$ and pH 6.4. Each cross was planted in one row plot of 2-m long spaced 50 cm between rows and 20 cm between plants. The fertilizers applied were 12-24-12 (N, $P_2O_5$ and $K_2O$) at the rate of 187.5 kg/ha. Manual hand weeding was made as needed. Data were collected on individual plants for seed size, pods/plant, pod length and yield. The analysis of variance for genetic effects was estimated by using the method described by Griffing (1956), Model II (Random Model) and by a computer model Diallel Analysis and Simulation Software by Burow and Coors (1993).

**Table 1. A half diallel of six varieties/lines of mungbean.**

| Variety/line | SUT1 | KPS1 | V3273 | VC1173A | VC1210A | V4718 |
|---|---|---|---|---|---|---|
| SUT1 | selfed | X | X | X | X | X |
| KPS1 | | selfed | X | X | X | X |
| V3273 | | | selfed | X | X | X |
| VC1173A | | | | selfed | X | X |
| VC1210A | | | | | selfed | X |
| V4718 | | | | | | selfed |

where X = direct cross.

### 2. $F_2$ generation

Seeds of each $F_1$ cross were harvested in bulk as well as their respective parents and were planted in a randomized complete block design with 4 replications. In each replication the seeds of each cross were planted in 3 rows of 4 m in length, spaced 50 cm between rows and 20 cm between hills with one plant/hill. Characters measured were biomass, height, total dry matter, 100-seed weight, pod length, seeds/pod, pods/plant, seeds/plant, seed weight/plant and seed yield.

The general and specific combining ability were analyzed by using Griffing's method (1956) for gene action study. Heritability was estimated from the genetic variance of the components. Heterosis was obtained by using means of $F_1$ and $F_2$. The relation of seed size with other characters was based on genetic and phenotypic correlation. Besides path coefficient of yield component, yield and seed size were studied on the direct effect and component compensation that would occur between the characters.

## 3. Statistical Analysis

### 3.1 Genetic effects

The Model II, Method II of Griffing (1956), assuming genotypes as random effect, was used for combining ability analysis of $F_1$ and $F_2$ as follows:

$$X_{ijk} = m + g_i + g_j + s_{ij} + b_k + e_{ijk}$$

where, m = population mean

$g_i$ = GCA effect for parent i

$g_j$ = GCA effect for parent j

$s_{ij}$ = SCA effect for parent i and j

$b_k$ = replication (block) effect for block k

$e_{ijk}$ = error

On the basis of the expected mean squares, estimates of GCA variance ($\sigma^2_{GCA}$), SCA variance ($\sigma^2_{SCA}$) and environmental variance ($\sigma^2$) were obtained for each trait. Additive genetic variance ($\sigma^2_A$), dominance genetic variance ($\sigma^2_D$) and $\sigma^2$ were estimated as:

$$\sigma^2_{GCA} = \tfrac{1}{2}\,\sigma^2_A \quad \text{or} \quad 2\,(\sigma^2_{GCA}) = \sigma^2_A\,;$$

$$\sigma^2_{SCA} = \sigma^2_D\,;$$

$$\sigma^2_{error} = \sigma^2$$

### 3.2 Heritability

The average level of dominance was calculated for all traits assuming allele frequencies of 0.5 for segregating loci. Narrow-sense ($h^2_n$) and broad-sense ($h^2_b$) heritability was calculated from the estimated components of variance as:

$$h^2_n = \sigma^2_A / (\sigma^2_A + \sigma^2_D + \sigma^2)$$

$$h^2_b = (\sigma^2_A + \sigma^2_D) / (\sigma^2_A + \sigma^2_D + \sigma^2)$$

### 3.3 The relative importance of effects

The relative importance of additive and non additive effect was assessed by the ratio of the variances proposed by Baker (1978) as:

$$\text{The relative importance} = \sigma^2_A / \sigma^2_A + \sigma^2_D$$

### 3.4 Heterosis

Heterosis (%) was calculated based on mid-parent value of $F_1$ and $F_2$ for 100-seed weight as well as other characters except yield. For yield trait the heterosis was based on high-parent value as:

$$\text{Heterosis (\%)} = \frac{F_{1\ \text{or}}\ F_2 - \text{MP (or HP)}}{\text{MP (or HP)}} \times 100$$

where $F_{1\ \text{or}}\ F_2$ was hybrid mean of first or second generation. MP was the mid-parent value and HP the high-parent value.

Diallel Analysis and Simulation Software by Burow and Coors (1993) was used in this study. The model in the software assumes that epistasis and genotype x environment interaction are not significant. All the characters measured in the field and laboratory were analyzed by using IRRI STAT Version 9/93 Program and comparing the character means by DMRT and LSD, The F-test for variances was identified at 0.05 and 0.01 level of probability.

### 3.5 Phenotypic and genotypic correlation coefficient

Phenotypic and genotypic correlations based on the correlation coefficient (*r*) provide a measure of the relationship between traits and serve to assess the chance for improvement of two traits by common selection for one trait to identify superior genotypes with a related trait. The calculated value of a correlation coefficient applies only to the genetic material in a particular experiment and the environment in which the experiment is grown, but similar correlation coefficients over a series of experiments with a range of genetic materials and environments may provide substantial productive value. The interpretation of the correlation coefficient will be enhanced if information on the genetic materials in the experiment and the environment in which it was conducted is reported along with the *r* value. In this experiment both phenotypic and genotypic correlation coefficients were calculated from analysis of variance and values in correlation coefficient table were used for testing significance.

### 3.6 Path-coefficient analysis

Path-coefficient analysis is based on correlation studies. It is important that selection to increase one trait does not lead to deterioration in other traits. So, the relationship between traits expressed by the correlation coefficient may be partitioned into direct and indirect contributions of component traits toward the expression of a related trait. As with correlation analysis, a path-coefficient analysis of a specific experiment is applicable only to the genetic material used in the experiment and the environment in which the experiment is conducted.

# Results and Discussion

## 1. GCA effects in $F_1$ population

Estimates of GCA effects quantitatively measured the comparative performance of parents (or cross combinations) in relation to another one. Analysis of variance of diallel crosses and estimated GCA effects of $F_1$ generation for five characters are presented in Tables 2 and 3. Significant GCA for seed size was found for all parents. Positive GCA was found for large-seeded varieties, SUT1 and KPS1 (1.35 and 0.70, respectively) and negative GCA for varieties from AVRDC which were small-seeded parents (V4718, VC1173A and V3273 as -1.04, -0.92 and –0.26, respectively). Although VC1210A was classified in small-seeded group, it had larger seed size than others of the same class and showed positive GCA, even though the value was small. This result indicated that VC1210A was not a good combiner as compared with SUT1 and KPS1 for improving seed size character.

Large-seeded varieties with positive GCA effects for seed size were observed having either positive or negative GCA for other yield components. One possible explanation could be the compensation between seed size and other yield components following the seed size had been improved.

Table 2. Analysis of variance for seed size and other characters of diallel crosses involving six varieties/lines of mungbean in $F_1$ population.

| Source | df | Mean squares | | | | |
|---|---|---|---|---|---|---|
| | | Seed size | Pods/plant | Seeds/pod | Seeds/ plant | Yield/plant |
| Replication | 2 | 0.16ns | 24.66ns | 0.86ns | 583.1 ns | 0.32ns |
| Crosses | 20 | 5.62** | 186.04** | 2.74* | 13,213.3* | 20.17** |
| GCA | 5 | 20.80** | 266.35ns | 6.39* | 26,645.64* | 23.15ns |
| SCA | 15 | 0.56** | 159.26** | 1.52ns | 8,735.9** | 19.17** |
| Error | 40 | 0.21 | 26.31 | 1.24 | 1,815.6 | 4.84 |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

Table 3. Means and general combining ability (GCA) of mungbean varieties/lines of $F_1$ population.

| Variety/line | Seed size (g/100 seeds) |  | No. pods/plant |  | No. seeds/pod |  | No. seeds/plant |  | Yield/plant (g) |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Mean | GCA | Mean | GCA | Mean | GCA | Mean | GCA | Mean | GCA |
| SUT1 | 6.70 | 1.35** | 21.11 | -2.02* | 7.46 | -0.94** | 154.0 | -39.1** | 8.62 | -1.27** |
| KPS1 | 6.02 | 0.70** | 19.00 | -4.98** | 8.71 | 0.41ns | 161.2 | -34.8** | 9.74 | 0.01ns |
| V3273 | 5.10 | -0.26** | 22.83 | -0.98ns | 8.51 | 0.23ns | 194.7 | -0.68ns | 9.12 | -0.40ns |
| VC1173A | 4.41 | -0.92** | 27.06 | 4.35** | 8.78 | 0.45* | 235.9 | 50.11** | 10.11 | 0.71ns |
| VC1210A | 5.51 | 0.18* | 23.67 | 2.06* | 8.26 | -0.08ns | 191.3 | 12.49ns | 10.12 | 1.50** |
| V4718 | 4.28 | -1.04** | 25.17 | 1.56** | 8.38 | -0.07ns | 210.2 | 11.99ns | 9.15 | -0.55ns |
| SE |  | 0.1 |  | 1.0 |  | 0.2 |  | 7.9 |  | 0.4 |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

## 2. GCA effects in $F_2$ population

Analysis of variance of diallel crosses and estimated GCA of $F_2$ population were presented in Tables 4 and 5. Significant values were observed for all parents, but only SUT1, KPS1 and VC1210A were positive. It should be noted that these three genotypes had seed size over 5 g per 100 seeds. SUT1 appeared to be a good source for large seed size as indicated by highest GCA, and that of KPS1 was in between SUT1 and VC1210A. The rest three lines showed negatively significant GCA which suggested that they were unsuitable source for increasing seed size. From these results it can be concluded that SUT1 and KPS1 were the best choice for large seed character in mungbean improvement.

In addition to highly positive GCA for seed size of SUT1 and KPS1, these genotypes also showed significantly positive GCA for seed yield per plant and pod length (Table 5). Although negative effects were found for almost all of other characters studied, only significant GCA was observed on the number of seeds per pod. It is interesting to note that SUT1 had higher values than KPS1. Due to higher negative values as compared to KPS1, SUT1 would contribute less number of seeds per pod and number of seeds per plant when used as a parent in crosses. However, these traits were compensated by larger seed size which resulted in longer pod and higher seed yield per plant.

Both positive and negative GCA effects were found for the number of pods per plant, biomass and total dry matter, although they were not significant in both groups of large- and small-seeded parents. It might be difficult to improve these characters simultaneously using these parents. However, it may be possible to

Table 4. Analysis of variance for seed size and other characters of diallel crosses involving six varieties/lines of mungbean in $F_2$ population.

| | | Mean squares | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source | df | Seed size | Pods/plant | Seeds/pod | Seeds/plant | Yield/Plant | Pod length | Biomass | Total dry matter | Plant height |
| Replication | 3 | 0.10ns | 221.22* | 0.40ns | 19,671.06* | 31.34** | 0.68* | 1,153.53ns | 130.48ns | 49.41ns |
| Crosses | 20 | 5.40** | 166.87** | 1.97** | 12,004.43** | 23.27** | 2.57** | 2,958.60** | 279.38** | 117.41** |
| GCA | 5 | 19.87** | 484.52** | 5.35** | 32,825.44** | 78.16** | 8.76** | 2,311.18ns | 355.07ns | 318.95** |
| SCA | 15 | 0.58** | 60.99 ns | 0.84 ns | 5,064.09 ns | 4.97 ns | 0.51** | 3,174.40** | 254.15** | 50.23* |
| Error | 60 | 0.07 | 55.51 | 0.78 | 4,865.96 | 6.63 | 0.17 | 923.65 | 73.37 | 24.22 |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

Table 5. Means and general combining ability (GCA) of mungbean varieties/lines of $F_2$ population.

| | Seed size (g/100 seeds) | | No. pods/plant | | No. seeds/pod | | No. seeds/plant | | Yield/plant (g) | | Pod length (cm) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety/line | Mean | GCA | Mean | GCA | Mean | GCA | Mean | GCA | Mean | GCA | Mean | GCA |
| SUT1 | 6.08 | 1.09** | 29.25 | 0.56ns | 9.43 | -0.62** | 187.59 | -21.25ns | 10.81 | 0.96* | 8.90 | 0.75** |
| KPS1 | 5.56 | 0.66** | 27.92 | -1.00ns | 9.60 | -0.36* | 206.42 | -4.57ns | 10.56 | 0.93* | 8.31 | 0.26** |
| V3273 | 4.55 | -0.39** | 31.17 | 2.86* | 10.38 | 0.29* | 235.49 | 29.76* | 10.29 | 0.70ns | 7.90 | -0.24** |
| VC1173A | 3.97 | -0.93** | 33.51 | 4.78** | 10.45 | 0.45** | 247.33 | 41.36** | 9.62 | 0.002ns | 7.47 | -0.61** |
| VC1210A | 5.15 | 0.21** | 27.47 | -0.63ns | 10.25 | 0.19ns | 205.92 | 0.08ns | 9.98 | 0.51ns | 8.40 | 0.30** |
| V4718 | 4.26 | -0.65** | 22.37 | -6.56** | 10.13 | 0.04ns | 168.25 | -45.38** | 6.67 | -3.11** | 7.58 | -0.46** |
| SE | | 0.04 | | 1.20 | | 1.14 | | 11.27 | | 0.42 | | 0.07 |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

**Table 5. continued.**

| Variety/line | Biomass per plant (g) | | Total dry matter per plant (g) | | Height (cm) | |
|---|---|---|---|---|---|---|
| | Mean | GCA | Mean | GCA | Mean | GCA |
| SUT1 | 138.66 | -6.27ns | 33.83 | -0.74ns | 67.23 | -4.90** |
| KPS1 | 153.22 | 6.88ns | 36.72 | 2.33ns | 71.75 | -1.18ns |
| V3273 | 139.70 | -4.32ns | 32.52 | -0.0004ns | 75.86 | 3.63** |
| VC1173A | 143.96 | -0.97ns | 34.79 | 0.72ns | 71.34 | -1.17ns |
| VC1210A | 163.60 | 13.39** | 38.32 | 3.66* | 72.88 | 0.51ns |
| V4718 | 138.50 | -8.70ns | 28.68 | -5.97** | 75.91 | 3.11** |
| SE | | 4.9 | | 1.4 | | 0.8 |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

improve each character in separate selection efforts or to improve one without significantly decreasing the other. In particular V4718, a late flowering line from AVRDC, gave hybrid combinations that showed low performance on all traits studied except height (Table 5).

The only one small-seeded genotype worth mentioning was VC1173A. This genotype showed highly positive GCA for the number of pods per plant, number of seeds per pod, and number of seeds per plant. However, it was not a good genetic source for improving large seed and pod length (Table 5).

Among all six genotypes SUT1 was shortest plant in height and significantly reduced plant height in $F_2$ population, while V3273 and V4718 were tallest and significantly increased plant height.

### 3. SCA effects in $F_1$ population

Estimates of SCA effects on seed size in $F_1$ generations were either negatively or positively significant in six crosses as shown in Table 6. These results indicated that the varieties/lines used in the study were more diverse in seed size than other characters. The number of pods per plant also showed similar SCA effects as seed size in several crosses, indicating significant difference in number of pods per plant of the parents that contributed to the progeny.

Another character that showed significantly negative SCA effects in three crosses was the number of seeds per plant. Although it was not statistically significant, most crosses showed either positive or negative SCA effects which indicated the difference in the number of seeds per plant of the parents. Noteworthy was the cross SUT1 x KPS1 that gave the lowest seeds per plant (98 seeds) (Table 6). This cross also showed positive heterotic effects on seed size and seed yield per plant (4.59 and 27.78 percent, respectively) (Table 8), although the latter was not among the highest. It seemed likely that SUT1 could increase seed size character when in appropriate cross combination especially with KPS1 and V3273. This remark was supported by the positive SCA effects (Table 6) on seed size. KPS1 was also a source for seed size character, but only when crossed with V4718 that showed 8.86 % heterosis, yet its $F_1$ seed size was much smaller than that of SUT1 (Table 8).

Table 6. Means and specific combining ability (SCA) effects of 15 crosses in $F_1$ generation.

| | Seed size (g/100seeds) | | No. pods/plant | | No. seeds/pod | | No. seeds/plant | | Yield/plant (g) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cross | Mean | SCA | Mean | SCA | Mean | SCA | Mean | SCA | Mean | SCA |
| SUT1xKPS1 | 7.74 | 0.36ns | 12.17 | -4.95ns | 8.08 | 0.34ns | 98.0 | -25.26ns | 8.97 | 0.64ns |
| SUT1xV3273 | 7.02 | 0.60* | 17.50 | -3.62ns | 8.15 | 0.59ns | 142.3 | -15.05ns | 9.72 | 1.80ns |
| SUT1xVC1173A | 5.25 | -0.52* | 27.00 | 0.55ns | 7.83 | 0.05ns | 211.7 | 3.49ns | 8.81 | -0.23ns |
| SUT1xVC1210A | 6.64 | -0.22ns | 23.33 | -0.83ns | 7.43 | 0.19ns | 174.3 | 3.79ns | 10.72 | 0.90ns |
| SUT1xV4718 | 5.57 | -0.07ns | 20.67 | -2.99ns | 7.67 | 0.41ns | 154.3 | -15.71ns | 8.19 | 0.41ns |
| KPS1xV3273 | 4.81 | -0.96** | 25.50 | 7.34** | 7.92 | -0.99ns | 203.0 | 41.33ns | 9.64 | 0.44ns |
| KPS1xVC1173A | 5.05 | -0.06ns | 27.67 | 4.17ns | 9.01 | -0.12ns | 234.7 | 22.20ns | 12.04 | 1.73ns |
| KPS1xVC1210A | 6.14 | -0.08ns | 13.33 | -7.87** | 9.84 | 1.24* | 131.0 | -43.84ns | 8.07 | -3.03* |
| KPS1xV4718 | 5.53 | 0.54* | 20.33 | -0.37ns | 8.41 | -0.20ns | 166.3 | -8.01ns | 10.98 | 1.93ns |
| V3273xVC1173A | 4.41 | 0.26ns | 21.67 | -5.83* | 9.12 | 0.17ns | 197.7 | -48.92* | 9.94 | 0.04ns |
| V3273xVC1210A | 5.84 | 0.59* | 21.00 | -4.20ns | 7.73 | -0.68ns | 163.3 | -45.63* | 6.36 | -4.33** |
| V3273xV4718 | 3.86 | -0.17ns | 27.33 | 2.63ns | 9.42 | 1.00ns | 255.0 | 46.54* | 9.93 | 1.29ns |
| VC1173AxVC1210A | 4.72 | 0.12ns | 16.67 | -13.87** | 8.54 | -0.10ns | 141.7 | -118.1** | 8.44 | -3.36** |
| VC1173AxV4718 | 3.45 | 0.07ns | 28.00 | -2.04ns | 9.37 | 0.72ns | 264.7 | 5.41ns | 9.32 | -0.43ns |
| VC1210AxV4718 | 3.95 | -0.53* | 24.33 | -3.41ns | 8.40 | 0.29ns | 205.7 | -15.96ns | 8.68 | -1.86ns |
| SE | | 0.237 | | 2.625 | | 0.569 | | 21.806 | | 1.126 |

*, ** significant at 0.05 and 0.01 level respectively; ns = nonsignificant.

The number of seeds per pod was the only trait that showed less variation among yield component traits which was indicated by the small SCA values of almost all crosses except KPS1 x VC1210A (Table 6). Similar results were obtained for seed yield per plant. Although significant negative SCA effects were found in a few crosses, this was probably associated with negative SCA for the number of pods per plant.

## 4. SCA effects in $F_2$ population

Estimated SCA effects in $F_2$ generations for nine characters are shown in Table 7. Eight crosses were found significant SCA effects for seed size, four crosses were positive and four negative. The crosses with significant positive SCA were SUT1 x V3273, VC1173A x VC1210A, SUT1 x V4718 and KPS1 x VC1210A with the values of 0.97, 0.47, 0.38 and 0.25, respectively. These crosses involved parents with a high and positive GCA effect (Table 5) (SUT1 = 1.09, KPS1 = 0.66 and VC1210A = 0.21). The other four crosses with negative SCA effects were V3273 x V4718 (-0.40), SUT1 x VC1173A (-0.36), KPS1 x VC1173A (-0.33) and VC1210A x V4718 (-0.28). These crosses also had one parent having high and negative GCA in each cross (VC1173A = -0.93 and V4718 = -0.65).

Significant positive SCA effects were found for the number of pods per plant in two crosses (KPS1 x VC1173A and VC1210A x V4718). For the number of seeds per pod, significant SCA effect was found only in SUT1 x VC1210A cross (0.84). Positive SCA effect was found only in VC1210A x V4718 (87.04) for the number of seeds per plant. Seed yield did not show significant SCA effect. Significant SCA effect for pod length was observed in two crosses, SUT1 x V3273 (1.05) and V3273 x V4718 (-0.46).

## 5. Heterosis in $F_1$ population

Mean values of the parents and $F_1$ progenies and the heterotic effects for seed yield and yield components are presented in Table 8. Only 6 hybrids showed positive heterosis while other 8 hybrids had negative heterosis for seed size which indicated that the small seed size had more pronounced effect over large seed. In general, it can be said that hybrid vigor for seed size in mungbean was fairly low with the highest value approximately 10 % in two crosses. Negative heterotic effects were observed in many more crosses than positive heterosis. This occurred when a small-seeded parent was involved. The most reduced heterosis was found in a cross KPS1 x V3273 (-16.20 %). The overall average heterosis of –0.45 % indicated the limitation for improving seed size through the use of genotypes included in this study

Table 7. Means and specific combining ability (SCA) effects of 15 crosses in $F_2$ generation.

| | Seed size (g/100 seeds) | | No. pods/plant | | No. seeds/pod | | No. seeds/plant | | Yield/plant (g) | | Pod length (cm) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cross | Mean | SCA | Mean | SCA | Mean | SCA | Mean | SCA | Mean | SCA | Mean | SCA |
| SUT1xKPS1 | 6.70 | 0.02ns | 32.20 | 4.17ns | 8.39 | -0.64ns | 237.25 | 55.56ns | 12.88 | 1.39ns | 8.84 | -0.26ns |
| SUT1xV3273 | 6.59 | 0.97** | 31.87 | -0.02ns | 10.30 | 0.62ns | 206.00 | -10.02ns | 13.41 | 2.17ns | 9.65 | 1.05** |
| SUT1xVC1173A | 4.72 | -0.36** | 33.73 | -0.07ns | 9.72 | -0.12ns | 222.00 | -5.63ns | 10.77 | 0.22ns | 8.04 | -0.18ns |
| SUT1xVC1210A | 6.03 | -0.19ns | 27.99 | -0.40ns | 10.42 | 0.84* | 176.75 | -9.59ns | 10.66 | -0.40ns | 9.14 | -0.01ns |
| SUT1xV4718 | 5.74 | 0.38** | 21.43 | -1.04ns | 9.16 | -0.28ns | 126.50 | -14.38ns | 7.18 | -0.26ns | 8.53 | 0.16ns |
| KPS1xV3273 | 5.04 | -0.15ns | 28.13 | -2.20ns | 9.99 | 0.05ns | 217.50 | -15.20ns | 10.20 | -1.01ns | 8.13 | 0.03ns |
| KPS1xVC1173A | 4.32 | -0.33** | 39.13 | 6.88* | 9.82 | -0.27ns | 279.00 | 34.70ns | 11.74 | 1.23ns | 7.70 | -0.02ns |
| KPS1xVC1210A | 6.04 | 0.25* | 23.82 | -3.02ns | 10.01 | 0.17ns | 180.00 | -23.02ns | 10.52 | -0.51ns | 8.82 | 0.18ns |
| KPS1xV4718 | 4.91 | -0.02ns | 20.44 | -0.47ns | 9.85 | 0.16ns | 147.25 | -10.30ns | 6.88 | -0.53ns | 7.66 | -0.22ns |
| V3273xVC1173A | 3.47 | -0.14ns | 39.56 | 3.46ns | 10.89 | 0.06ns | 288.50 | 9.86ns | 10.16 | -0.12ns | 7.25 | 0.02ns |
| V3273xVC1210A | 4.70 | -0.05ns | 27.57 | -3.12ns | 10.40 | -0.09ns | 217.25 | -20.10ns | 10.01 | -0.78ns | 8.12 | -0.03ns |
| V3273xV4718 | 3.49 | -0.40** | 24.75 | 0.01ns | 10.75 | 0.41ns | 206.00 | 14.11ns | 7.09 | -0.08ns | 6.92 | -0.46* |
| VC1173AxVC1210A | 4.68 | 0.47** | 26.68 | -5.93ns | 10.24 | -0.42ns | 194.50 | -54.46ns | 8.79 | -1.31ns | 7.90 | 0.13ns |
| VC1173AxV4718 | 3.48 | 0.13ns | 25.58 | -1.11ns | 11.12 | 0.62ns | 200.50 | -2.99ns | 6.87 | 0.39ns | 7.11 | 0.10ns |
| VC1210AxV4718 | 4.20 | -0.28* | 29.38 | 8.10* | 10.29 | 0.04ns | 249.25 | 87.04* | 8.65 | 1.66ns | 7.82 | -0.11ns |
| SE | | 0.114 | | 3.302 | | 0.392 | | 30.916 | | 1.141 | | 0.185 |

*, ** significant at 0.05 and 0.01 level respectively; ns = nonsignificant.

**Table 7. continued.**

| | Biomass (g) | | Total dry matter (g) | | Plant height (cm) | |
|---|---|---|---|---|---|---|
| Cross | Mean | SCA | Mean | SCA | Mean | SCA |
| SUT1xKPS1 | 109.68 | -36.44** | 28.90 | -6.75ns | 67.30 | 1.17ns |
| SUT1xV3273 | 130.58 | -4.35ns | 31.22 | -2.09ns | 68.12 | -2.81ns |
| SUT1xVC1173A | 181.54 | 43.26** | 43.74 | 9.70* | 69.82 | 3.69ns |
| SUT1xVC1210A | 121.34 | -31.29* | 30.17 | -6.80ns | 64.70 | -3.12ns |
| SUT1xV4718 | 152.35 | 21.80ns | 39.46 | 12.12** | 70.58 | 0.15ns |
| KPS1xV3273 | 129.10 | -18.98ns | 32.64 | -3.75ns | 73.48 | -1.18ns |
| KPS1xVC1173A | 158.94 | 7.51ns | 42.80 | 5.70ns | 71.62 | 1.77ns |
| KPS1xVC1210A | 221.26 | 55.48** | 53.81 | 13.77** | 69.62 | -1.91ns |
| KPS1xV4718 | 145.95 | 2.25ns | 25.39 | -5.03ns | 83.00 | 8.86** |
| V3273xVC1173A | 125.08 | -15.15ns | 26.27 | -8.51* | 74.80 | 0.14ns |
| V3273xVC1210A | 183.80 | 29.21* | 40.72 | 3.01ns | 80.72 | 4.38* |
| V3273xV4718 | 123.76 | -8.75ns | 21.06 | -7.03ns | 78.75 | -0.20ns |
| VC1173AxVC1210A | 135.65 | -22.28ns | 30.20 | -8.24* | 72.80 | 1.26ns |
| VC1173AxV4718 | 115.51 | -20.34ns | 30.30 | 1.49ns | 71.00 | -3.14ns |
| VC1210AxV4718 | 175.44 | 25.23ns | 37.26 | 5.51ns | 77.25 | 1.43ns |
| SE | | 13.5 | | 3.8 | | 2.2 |

*, ** significant different at the 5 % and 1% level, respectively.

ns = nonsignificant.

Negative heterosis for seed size in mungbean was also reported previously (Ghafoor *et al*., 1990; Sekhar *et al*., 1994; Khattak *et al*., 2002a).

As mentioned before the highest positive heterosis for seed size in mungbean in this study was only 10 % which suggested that appropriate crosses be made so that the selection for large seed segregates could be obtained. In this study, however, the cross SUT1 x KPS1 would likely be the best choice for large seed since both parents possesses this character, even though the heterosis was not as high as some other crosses but the $F_1$ population had very large seed (7.74 g/100 seeds).

For the number of pods per plant, only two crosses had positive heterosis, with the highest value of 30.77 % for the cross KPS1 x V3273. The rest besides these two crosses showed negative heterosis, with the highest value of –60.55 % for the cross VC1173A x VC1210A. It was also the same cross that showed highly negative heterosis for seed size (-9.40 %), number of seeds per plant (-59.31%), and seed yield per plant (-44.76 %). The overall heterosis was still negative (-24.88 %). High heterotic effects observed in this study were similar to earlier findings in which high heterotic effects for the number of pods per plant were observed in chickpea, urdbean and mungbean (Malik *et al*., 1987; Shinde and Deshukh, 1981; Khattak *et al*. 2002a). Only two out of 15 crosses showed positive heterosis for the number of seeds per plant (19.41 and 20.85 %). Both crosses involved V3273 as a parent (Table 8). It was observed that perhaps this parent contributed a high number of seeds because when in combination with KPS1 (which contained low number of seed) increased seed number per plant was obtained. This cross (KPS1 x V3273 showing 19.41 % heterosis) would offer opportunity for selection for both large seed and high number

Table 8. Heterosis in $F_1$ population.

| | seed size (g/100 seeds) | | | Pods/plant (no.) | | | Seeds/pod (no.) | | | Seeds/plant (no.) | | | Yield (g/plant) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cross | MP | $F_1$ | Heterosis | MP | $F_1$ | Heterosis | MP | $F_1$ | Heterosis | MP | $F_1$ | Heterosis | HP | $F_1$ | Heterosis |
| SUT1xKPS1 | 7.40 | 7.74 | 4.59 | 20.50 | 12.20 | -40.49 | 7.48 | 8.08 | 8.02 | 139 | 98 | -29.50 | 8.76 | 8.97 | 2.40 |
| SUT1xV3273 | 6.31 | 7.02 | 11.25 | 25.00 | 17.50 | -30.00 | 7.14 | 8.15 | 14.15 | 175 | 142 | -18.86 | 9.16 | 9.72 | 6.11 |
| SUT1xVC1173A | 5.77 | 5.25 | -9.01 | 33.70 | 27.00 | -19.88 | 7.41 | 7.83 | 5.67 | 254 | 212 | -16.54 | 12.14 | 8.81 | -27.43 |
| SUT1xVC1210A | 6.86 | 6.64 | -3.21 | 34.70 | 23.30 | -32.85 | 6.82 | 7.43 | 8.94 | 238 | 174 | -26.89 | 18.43 | 10.72 | -41.83 |
| SUT1xV4718 | 5.65 | 5.57 | -1.42 | 28.20 | 20.70 | -26.60 | 6.51 | 7.67 | 17.82 | 179 | 154 | -13.97 | 7.82 | 8.19 | 4.73 |
| KPS1xV3273 | 5.74 | 4.81 | -16.20 | 19.50 | 25.50 | 30.77 | 8.83 | 7.92 | -10.31 | 170 | 203 | 19.41 | 9.16 | 9.64 | 5.24 |
| KPS1xVC1173A | 5.20 | 5.05 | -2.88 | 28.20 | 27.70 | -1.77 | 8.90 | 9.01 | 1.24 | 250 | 235 | -6.00 | 12.14 | 12.04 | -0.008 |
| KPS1xVC1210A | 6.30 | 6.14 | -2.54 | 29.20 | 13.30 | -54.45 | 8.30 | 9.84 | 18.55 | 233 | 131 | -43.78 | 18.43 | 8.07 | -56.21 |
| KPS1xV4718 | 5.08 | 5.53 | 8.86 | 22.70 | 20.30 | -10.57 | 7.99 | 8.41 | 5.26 | 175 | 166 | -5.14 | 8.76 | 10.98 | 25.34 |
| V3273xVC1173A | 4.11 | 4.41 | 7.30 | 32.70 | 21.70 | -33.64 | 8.75 | 9.12 | 4.23 | 286 | 198 | -30.77 | 12.14 | 9.94 | -18.12 |
| V3273xVC1210A | 5.21 | 5.84 | 12.09 | 33.70 | 21.00 | -37.69 | 8.16 | 7.73 | -5.27 | 269 | 163 | -39.41 | 18.43 | 6.36 | -65.49 |
| V3273xV4718 | 4.00 | 3.86 | -3.50 | 27.20 | 27.30 | 0.37 | 7.85 | 9.42 | 20.00 | 211 | 255 | 20.85 | 9.16 | 9.93 | 8.41 |
| VC1173AxVC1210A | 4.66 | 4.72 | 1.18 | 42.33 | 16.70 | -60.55 | 8.23 | 8.54 | 3.77 | 349 | 142 | -59.31 | 18.43 | 8.44 | -54.21 |
| VC1173AxV4718 | 3.45 | 3.45 | 0.00 | 35.83 | 28.00 | -21.85 | 7.92 | 9.37 | 18.31 | 290 | 265 | -8.62 | 12.14 | 9.32 | -23.23 |
| VC1210AxV4718 | 4.55 | 3.95 | -13.19 | 36.83 | 24.3 | -34.02 | 7.32 | 8.40 | 14.75 | 274 | 206 | -24.82 | 18.43 | 8.68 | -52.90 |
| Average | | | -0.45 | | | -24.88 | | | 8.34 | | | -18.89 | | | -19.15 |

of seeds per plant. It must be noted, however, that this yield component trait was variable.

Thirteen crosses showed positive heterotic effect, ranging from 1.24 to 20 %, for the number of seeds per pod. It seemed that the lines with small seed size contributed a high number of seeds per pod trait. Negative effect was observed in two crosses. As the average heterosis was low (8.34 %), so it would offer less potential for selecting good lines except for some crosses. As might be expected for a quantitative trait like seed yield per plant, the heterosis varied greatly in both directions ranging from 34.44 % to –53.91 % with an average heterosis of –2.38 %. However, many crosses involving improved varieties (SUT1 and KPS1) had shown fairly high positive values and thus rendering potential of isolating high yielding plants as well as large seed size especially among progenies of crosses SUT1 x KPS1, SUT1 x V3273 and KPS1 x V4718 (Table 8).

### 6. Heterosis on $F_2$ population

In $F_2$ population the average heterosis for seed size became positive but still low (0.83 %) and half of the crosses showed positive effects (Table 9). The crosses SUT1 x KPS1 and SUT1 x V3273 were still showing positive heterosis (3.08 and 22.22 %, respectively) for this character as previously found in $F_1$ progenies, especially in the latter cross which indicated the potential of isolating large-seeded lines among the progenies in segregating population. Although many crosses showed positive heterosis, only a few had potential for large seed character. SUT1 x KPS1 had low heterosis value (3.08 %) but both parents had large seed size. As compared to the cross VC1173A x VC 1210A with 11.9 % heterosis, but the parents were small-seeded type. Thus it would be unlikely to isolate large-seeded lines from the $F_2$ population of the latter cross.

Many crosses showed high heterosis for the number of pods per plant, particularly crosses VC 1210A x V4718, KPS1 x VC1173A and SUT1 x KPS1 (40.0, 29.9 and 23.85 %, respectively), with an a average heterosis of 5.54 %. High heterosis and positive effects were reported in chickpea (Malik *et al*., 1987), urdbean (Shinde and Deshmukh, 1989) and mungbean (Khattak *et al*., 2002a). For the number of seeds per pod, 11 hybrids produced positive heterosis over mid-parent and 4 hybrids showed negative values. Maximum value of heterotic effect (10.64 %) was exhibited by the hybrid SUT1 x VC1210A. Average low heterosis was also previously reported in mungbean (Ghafoor *et al*., 1990; Khattak *et al*., 2002a).

For the number of seeds per plant, 7 hybrids showed positive and other seven possessed negative heterosis. Maximum heterosis of 67.11 % was exhibited by the VC1210A x V4718 cross followed by SUT1 x KPS1 (41.92 %). Average heterosis of $F_2$ population was 6.91 % for the number of seeds per plant (Table 9).

For seed yield per plant, 10 hybrids exhibited positive and 5 hybrids produced negative heterosis. Maximum heterosis (28.85 %) was expressed in hybrid SUT1 x V3273 followed by VC1210A x V4718 (24.29 %) and SUT1 x KPS1 (21.70 %). Average heterotic effect was 6.22 %, which was considered high and was previously observed in mungbean study (Khattak *et al*., 2002a). Each variety showed different effects in different cross combinations, therefore specific variety must be verified for improving seed yield character. Many experiments also showed positive midparent heterosis for pods/plant and seeds/pod (*Misra et al*., 1970; Singh and Jain, 1970;

Swindell and Poehlman, 1976). But midparent and high parent heterosis for seed weight was negative in several experiments (Singh and Jain, 1970; Swindell and Poehlman, 1976; Ko, 1979), indicating reductions in seed size which was also found in $F_1$ population in this study.

Eight hybrids exhibited positive heterosis for pod length character. Five showed negative heterosis and two had no heterosis. Maximum heterosis over mid-parent (16.87 %) was expressed in the cross SUT1 x V3273. Average heterosis was 0.86 % which was fairly low and similar result was reported by Sekhar *et al*. (1994) and Khattak *et al*. (2002a).

Seven hybrids showed positive heterosis for total fresh weight (biomass) and 8 hybrids were negative. Highest heterosis (48.32 %) was found in cross KPS1 x VC1210A followed by VC1210A x V4718 (33.79 %). From the results obtained, it could be concluded that specific cross combination must be considered if the breeding for improved biomass production is aimed.

For total dry weight 7 hybrids showed positive heterosis and eight were negative. Maximum heterosis (64.58 %) was found in cross SUT1 x V4718 followed by KPS1 x VC1210A (44.24 %). Although almost equal number of hybrids showing positive and negative heterosis was obtained, the higher percent positive heterosis made the average positive (4.04 %).

Plant height was measured at reproductive stage 6 (R6) on the same plants with biomass and total dry matter. Twelve hybrids exhibited positive heterosis and three were negative. The highest effect was observed in KPS1 x V4718 (18.23 %). Average heterosis of 3.48 % was similar to that of the biomass and dry matter production. Average heterosis of nine characters in $F_2$ population showed positive effect, therefore the improvement for these traits by a diallel method was posible. Seed size, pod length, and number of seeds per pod were low in value which indicated the additive gene effect. Six other characters with high values would indicate the control predominantly by dominance gene action rather than additive gene effect.

Table 9. Heterosis in $F_2$ population.

| | seed size (g/100 seeds) | | | No. pods/plant | | | No. seeds/pod | | | No. seeds/plant | | | Yield (g/plant) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cross | HP | $F_2$ | Heterosis | HP | $F_2$ | Hetetosis | HP | $F_2$ | Heterosis | HP | $F_2$ | Heterosis | HP | $F_2$ | Heterosis |
| SUT1xKPS1 | 6.5 | 6.7 | 3.08 | 26.0 | 32.2 | 23.85 | 9.1 | 8.4 | -7.69 | 167 | 237 | 41.92 | 11.17 | 12.9 | 15.49 |
| SUT1xV3273 | 5.4 | 6.6 | 22.22 | 31.7 | 31.9 | 0.63 | 9.3 | 10.3 | 10.75 | 217 | 206 | -5.07 | 10.89 | 13.4 | 23.05 |
| SUT1xVC1173A | 4.9 | 4.7 | -4.08 | 32.3 | 33.7 | 4.33 | 9.8 | 9.7 | -1.02 | 228 | 222 | -2.63 | 9.95 | 10.8 | 8.54 |
| SUT1xVC1210A | 6.0 | 6.0 | 0.00 | 28.8 | 28.0 | -2.78 | 9.4 | 10.4 | 10.64 | 187 | 177 | -5.35 | 11.28 | 10.7 | -5.14 |
| SUT1xV4718 | 5.2 | 5.7 | 9.62 | 20.4 | 21.4 | 4.90 | 9.1 | 9.2 | 1.10 | 119 | 127 | 6.72 | 9.95 | 7.2 | -27.64 |
| KPS1xV3273 | 5.2 | 5.0 | -3.85 | 29.5 | 28.1 | -4.75 | 9.8 | 10.0 | 2.04 | 228 | 218 | -4.39 | 11.17 | 10.2 | -8.68 |
| KPS1xVC1173A | 4.8 | 4.3 | -10.42 | 30.1 | 39.1 | 29.90 | 10.3 | 9.8 | -4.85 | 239 | 279 | 16.74 | 11.17 | 11.8 | 5.64 |
| KPS1xVC1210A | 5.8 | 6.0 | 3.45 | 26.6 | 23.8 | -10.53 | 9.8 | 10.0 | 2.04 | 198 | 180 | -9.09 | 11.28 | 10.5 | -6.91 |
| KPS1xV4718 | 5.0 | 4.9 | -2.00 | 18.2 | 20.4 | 12.09 | 9.6 | 9.9 | 3.13 | 129 | 147 | 13.95 | 11.17 | 6.9 | -38.23 |
| V3273xVC1173A | 3.6 | 3.5 | -2.78 | 35.8 | 39.6 | 10.61 | 10.5 | 10.8 | 2.86 | 289 | 289 | 0.00 | 10.89 | 10.2 | -6.34 |
| V3273xVC1210A | 4.6 | 4.7 | 2.17 | 32.3 | 27.6 | -14.55 | 10.1 | 10.4 | 2.97 | 248 | 217 | -12.50 | 11.28 | 10.0 | -11.35 |
| V3273xV4718 | 3.9 | 3.5 | -10.26 | 23.9 | 24.8 | 3.77 | 9.8 | 10.8 | 10.20 | 179 | 206 | 15.08 | 10.88 | 7.1 | -34.74 |
| VC1173AxVC1210A | 4.2 | 4.7 | 11.90 | 32.9 | 26.7 | -18.84 | 10.6 | 10.2 | -3.77 | 259 | 195 | -24.71 | 11.28 | 8.8 | -21.99 |
| VC1173AxV4718 | 3.5 | 3.5 | 0.00 | 24.5 | 25.6 | 4.49 | 10.3 | 11.1 | 7.77 | 190 | 201 | 5.79 | 9.38 | 6.9 | -26.44 |
| VC1210AxV4718 | 4.5 | 4.2 | -6.67 | 21.0 | 29.4 | 40.00 | 9.9 | 10.3 | 4.04 | 149 | 249 | 67.11 | 11.28 | 8.7 | -22.87 |
| Average | | | 0.83 | | | 5.54 | | | 2.68 | | | 6.91 | | | -10.51 |

Table 9. continued.

| | Pod length (cm) | | | Biomass (grams) | | | TDM (grams) | | | Height (cm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cross | MP | $F_2$ | Heterosis | MP | $F_2$ | Heterosis | MP | $F_2$ | Heterosis | MP | $F_2$ | Heterosis |
| SUT1xKPS1 | 9.0 | 8.8 | -2.22 | 145.4 | 109.7 | -24.55 | 33.1 | 28.9 | -12.69 | 64.2 | 67.3 | 4.83 |
| SUT1xV3273 | 8.3 | 9.7 | 16.87 | 141.2 | 130.6 | -7.51 | 36.4 | 31.2 | -14.29 | 71.1 | 68.1 | -4.22 |
| SUT1xVC1173A | 8.0 | 8.0 | 0.00 | 141.8 | 181.5 | 28.00 | 32.5 | 43.7 | 34.46 | 65.4 | 69.8 | 6.73 |
| SUT1xVC1210A | 8.9 | 9.1 | 2.25 | 140.3 | 121.3 | -13.54 | 33.6 | 30.2 | -10.12 | 67.5 | 64.7 | -4.15 |
| SUT1xV4718 | 8.3 | 8.5 | 2.41 | 127.3 | 152.4 | 19.72 | 24.0 | 39.5 | 64.58 | 68.9 | 70.6 | 2.47 |
| KPS1xV3273 | 8.0 | 8.1 | 1.25 | 150.1 | 129.1 | -13.99 | 40.0 | 32.6 | -18.50 | 72.4 | 73.5 | 1.52 |
| KPS1xVC1173A | 7.8 | 7.7 | -1.28 | 150.7 | 158.9 | 5.44 | 36.1 | 42.8 | 18.56 | 66.8 | 71.6 | 7.19 |
| KPS1xVC1210A | 8.7 | 8.8 | 1.15 | 149.2 | 221.3 | 48.32 | 37.3 | 53.8 | 44.24 | 68.9 | 69.6 | 1.02 |
| KPS1xV4718 | 8.1 | 7.7 | -4.94 | 136.2 | 146.0 | 7.20 | 27.7 | 25.4 | -8.30 | 70.2 | 83.0 | 18.23 |
| V3273xVC1173A | 7.1 | 7.3 | 2.82 | 146.5 | 125.1 | -14.61 | 39.3 | 26.3 | -33.08 | 73.7 | 74.8 | 1.49 |
| V3273xVC1210A | 8.0 | 8.1 | 1.25 | 145.0 | 183.8 | 26.76 | 40.5 | 40.7 | 0.49 | 75.8 | 80.7 | 6.46 |
| V3273xV4718 | 7.4 | 6.9 | -6.76 | 132.0 | 123.8 | -6.21 | 30.9 | 21.1 | -31.72 | 77.1 | 78.8 | 2.20 |
| VC1173AxVC1210A | 7.7 | 7.9 | 2.60 | 145.6 | 135.7 | -6.80 | 36.6 | 30.2 | -17.49 | 70.1 | 72.8 | 3.85 |
| VC1173AxV4718 | 7.1 | 7.1 | 0.00 | 132.6 | 115.5 | -12.90 | 27.0 | 30.3 | 12.22 | 71.4 | 71.0 | -0.56 |
| VC1210AxV4718 | 8.0 | 7.8 | -2.50 | 131.1 | 175.4 | 33.79 | 28.2 | 37.3 | 32.27 | 73.5 | 77.3 | 5.17 |
| Average | | | 0.86 | | | 4.61 | | | 4.04 | | | 3.48 |

TDM = Total dry matter

## 7. Genetic component variance

Estimates of genetic component variance for five characters were made in $F_1$ population as shown in Table 10. Seed size, number of seeds per pod and seed yield per plant showed less variance and number of seeds per plant was found highest estimated genetic variance than others. This result showed that the number of seeds per plant was more affected from other effects that not studied and from environment than other characters. Estimated additive relative importance ($\sigma^2_A/\sigma^2_A+\sigma^2_D$) showed seed size and number of seeds per pod were important for additive gene action more than others because the observed values were close to 1. Number of seeds per plant, pods per plant and seed yield per plant were low in the values which showed dominant gene action in these characters.

**Table** 10. **Estimates of the genetic components of variance, the error variance for the pooled random diallel in $F_1$ population of mungbean**.

| Characters | Additive variance ($\sigma^2_A$) | Dominance variance ($\sigma^2_D$) | Error variance ($\sigma^2$) | $\frac{\sigma^2_A}{\sigma^2_A + \sigma^2_D}$ |
|---|---|---|---|---|
| Seed size | 1.69 | 0.12 | 0.07 | 0.936 |
| No. pods/plant | 8.92 | 44.32 | 8.77 | 0.168 |
| No. seeds/pod | 0.41 | 0.09 | 0.41 | 0.812 |
| No. seeds/plant | 1,492.48 | 2,306.78 | 605.18 | 0.393 |
| Yield/plant | 0.33 | 4.78 | 1.615 | 0.065 |

Estimated genetic component variance for nine traits in $F_2$ population is shown in Table 11.

**Table 11. Estimates of the genetic components of variance, the error variance for the pooled random diallel in $F_2$ population of mungbean.**

| Characters | Additive Variance ($\sigma^2_A$) | Dominance variance ($\sigma^2_D$) | Error variance ($\sigma^2$) | $\frac{\sigma^2_A}{\sigma^2_A + \sigma^2_D}$ |
|---|---|---|---|---|
| Seed size | 1.21 | 0.12 | 0.02 | 0.908 |
| No. pods/plant | 26.47 | 1.37 | 13.88 | 0.951 |
| No. seeds/pod | 0.28 | 0.01 | 0.20 | 0.953 |
| No. seeds/plant | 1,735.08 | 49.53 | 1,216.49 | 0.972 |
| Yield/plant | 4.57 | 0.00 | 1.66 | 1.00 |
| Pod length | 0.52 | 0.08 | 0.04 | 0.861 |
| Plant height | 16.80 | 6.50 | 6.06 | 0.721 |
| Biomass/plant | 0.00 | 562.69 | 230.91 | 0.00 |
| TDM/plant | 6.31 | 45.20 | 18.34 | 0.122 |

TDM = total dry mater.

Three characters were low in variance for seed size, pod length and number of seeds per pod characters. Seed size as determined as 100-seed weight had low environmental effect ($\sigma^2$ = 0.02) which could be concluded that seed size was inherited by additive gene action rather than dominant gene effect. Francisco *et al.*

(2003) [On-line] found the additive-dominance model fitted the data for 100-seed weight in as much as the midparent value and the additive effect was the important genetic parameter for the determination of this character. Pod length and the number of seeds per pod also showed low environmental effects. Nevertheless, all traits were found higher additive variance than dominance variance except biomass and total dry matter characters. Biomass per plant and total dry matter had high dominant genetic variance with the relative importance of 0 and 0.122, respectively, which indicated that these characters were controlled by dominant gene action.

### 8. Phenotypic and genotypic correlation in $F_1$ population.

Phenotypic and genotypic correlations among characters in $F_1$ population are shown in Table 12. Seed size was significantly and negatively correlated phenotypically and genotypically with all characters studied. Negative phenotypic and genotypic correlations were observed between seed size and number of seeds per plant (-0.5636 and -0.6981, respectively), number of pods per plant (-0.4264 and -0.5165, respectively) and number of seeds per pod (-0.2923 and -0.5645, respectively). The phenotypic and genotypic correlations between seed size and seed yield per plant were lowest (-0.1205 and -0.1868, respectively) and negatively correlated. Seed size was also reported positively (Singh *et al*., 1968; Gupta and Singh, 1969; Yohe and Poehlman, 1975) or negatively (Malhotra *et al*., 1974) and significantly correlated phenotypically with seed yield. Khan (1985) also reported a significant positive phenotypic correlation ($r$ = 0.857) and a significant negative genotypic correlation ($r$ = -0.935) for seed weight versus seed yield. However, no comments were offered on why this may have occurred.

The data obtained from this study did not encourage the use of seed size as a selection criterion for improving seed yield. However, significant negative correlations between seed size and other yield components indicated the increase in one character would cause a decrease in the others. But it was evident that the increase in number of seeds per plant and pods per plant could increase seed yield per plant.

The negative correlation coefficients as well as phenotypic and genotypic correlations between seed size and most of the yield component traits obtained in $F_1$ population indicated that the breeding for improved seed size would sacrifice for the decrease in other characters. However, the data from insufficient $F_1$ materials might inflate the interpretation of the results. Therefore, the $F_2$ population must be considered as suggested by many studies (White, 1966; Verhalen and Murray, 1969; Bowman and Jones, 1984; Kao and McVetty, 1987; Choo *et al*., 1988).

Table 12. Phenotypic and genotypic (in parenthesis) correlations among characters of $F_1$ population of mungbean.

| Characters | No. pods/plant | No. seeds/pod | No. seeds/plant | Seed size | Yield/plant |
|---|---|---|---|---|---|
| Number of pods/plant | 1 | -0.2076ns | 0.9078** | -0.4264** | 0.5617** |
| | | (-0.1591) | (0.9534) | (-0.5165) | (0.6485) |
| Number of seeds/pod | | | 0.2016ns | -0.2923* | 0.1246ns |
| | | | (0.1433) | (-0.5645) | (0.3235) |
| Number of seeds/plant | | | | -0.5636** | 0.6132** |
| | | | | (-0.6981) | (0.6973) |
| Seed size | | | | | -0.1205ns |
| | | | | | (-0.1868) |
| Yield/plant | | | | | |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

Degree of freedom = 61

### 9. Phenotypic and genotypic correlation in $F_2$ population.

In $F_2$ population the phenotypic and genotypic correlations were quite different from those in $F_1$ population, especially between seed size and pod length which showed positive effect in the $F_2$ generation (Table 13). Similar result was also reported by Fraser *et al*. (1982) that pod length and width were positively correlated with seed size ($r = 0.90$ and 0.96, respectively). Negative correlations between seed size and other characters studied indicated that the selection for large seed size would decrease other characters except seed yield per plant. Upadhaya *et al*. (1980) also obtained positive correlation coefficient for 100-seed weight versus seed yield but only in the late-maturity group of mungbean cultivars. The selection for seed yield per plant would be effective and efficient by indirect selection for pod length, number of pods per plant, number of seeds per plant and seed size since positive values were obtained for both phenotypic and genotypic correlations. These results were similar to many experiments (Gupta and Singh, 1968; Singh, *et al*., 1968; Singh and Malhotra, 1970; Joshi and Kabaria, 1973; Malhotra *et al*., 1974; Parida and Singh, 1984).

Table 13. Phenotypic and genotypic (in parenthesis) correlations among characters of $F_2$ population of mungbean.

| Characters | Pod length | No. pods/plant | No. seeds/pod | No. seeds/plant | Seed size | Yield/plant |
|---|---|---|---|---|---|---|
| Pod length | 1 | -0.065 ns | -0.158 ns | -0.205 ns | 0.862** | 0.388** |
| | | (-0.110) | (-0.855) | (-0.451) | (0.995) | (0.689) |
| No. pods/plant | | | 0.050 ns | 0.877** | -0.106 ns | 0.819** |
| | | | (0.354) | (0.966) | (-0.164) | (0.653) |
| No. seeds/pod | | | | 0.176 ns | -0.490** | -0.288** |
| | | | | (0.645) | (-0.857) | (-0.030) |
| No. seeds/plant | | | | | -0.253* | 0.722** |
| | | | | | (-0.459) | (0.453) |
| Seed size | | | | | | 0.396** |
| | | | | | | (0.648) |
| Yield/plant | | | | | | |

*,** Significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant.

TDM = Total dry matter

Degree of freedom = 82

## 10. Path coefficients in $F_1$ population.

Path coefficients in $F_1$ population for the number of pods per plant, number of seeds per pod, number of seeds per plant and seed size are presented in Table 14. All traits were negatively correlated with seed size (final column), although not statistically significant with the number of seeds per pod. The number of pods per plant had negative direct effect on seed size (-0.3902), but showed small indirect effect through the number of seeds per pod (0.0036) and number of seeds per plant (-0.0064). The number of seeds per pod had negative direct effect, though not significantly (-0.1310), on seed size and low indirect effect through the number of pods per plant (0.0109) and number of seeds per plant (-0.0019). Significant negative effect of the number of seeds per plant on seed size was found with large indirect effect through the number of seeds per pod (-0.3650).

**Table 14. Path coefficients (diagonal), indirect effects (off diagonal) and correlation coefficients (final column) of some agronomic characters on weight of 100 seeds in $F_1$ population of mungbean.**

| Characters | No. pods/plant | No. seeds/pod | No. seeds/plant | Seed size |
|---|---|---|---|---|
| No. pods/plant | -0.3902 | 0.0036 | -0.0064 | -0.3900** |
| No. seeds/pod | 0.0109 | -0.1310 | -0.0019 | -0.1310ns |
| No. seeds/plant | -0.0068 | -0.3650 | -0.0357 | -0.4269** |

*,** = significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant

## 11. Path coefficient in $F_2$ population.

Path coefficients in $F_2$ population of four characters on seed size are shown in Table 15. Pod length and the number of seeds per pod had large direct effect on seed size (0.8503 and –0.4849, respectively). The number of seeds per plant contributed most but negative indirect effect on seed size (-0.2331). All these characters showed small indirect effect on seed size. These results indicated that the major contribution of some mungbean characters to seed size was from the length of pod, the number of seeds per pod and the number of seeds per plant. Therefore, the breeding to increase seed size must be to increase pod length while decreasing the number of seeds per pod and number of seeds per plant. With the exception of pod length all other characters showed negative effects (direct and indirect) on seed size. But in reality the breeding for increasing seed size by increasing pod length without increasing any other characters would be impossible. LeRoy *et al.* (1991a) reported both direct and indirect selection for small seed of soybean was effective in the temperate and tropical environments that were studied. The actual genetic gain averaged across environments and crosses for direct selection of seed weight was 6 mg/seed on a plant, 6 mg/seed on a plot, and 7 mg/seed on an entry-mean basis. Indirect selection by pod width resulted in an actual genetic gain of 6 mg/seed on a plant, 7 mg/seed on a plot, and 8 mg/seed on an entry-mean basis.

Based on these results it is likely that selection for plants that have the most seeds would result in large seed size, since this character (number of seeds per plant) had lower negative effect on seed size (-0.2331) than the number of seeds per pod

(-0.4502). Yet the latter had high direct effect on seed size (-0.4849) as compared with the previous one (-0.0032).

**Table 15. Path coefficients (diagonal), indirect effects (off diagonal) and correlation coefficients (final column) of some agronomic characters on weight of 100 seeds of $F_2$ population of mungbean.**

| Characters | pod length | No. pods/ plant | No. seeds/ pod | No. seeds/ plant | Seed size |
|---|---|---|---|---|---|
| Pod length | 0.8503 | 0.0035 | 0.0659 | 0.0005 | 0.8504** |
| No. pods/plant | -0.0304 | -0.0970 | -0.0237 | -0.0029 | -0.0949ns |
| No. seeds/pod | -0.1156 | -0.0047 | -0.4849 | -0.0005 | -0.4502** |
| No. seeds/plant | -0.1406 | -0.0862 | -0.0809 | -0.0032 | -0.2331* |

*,** = significantly different at 0.05 and 0.01 levels of probability, respectively.

ns = nonsignificant

### 12. Narrow sense and broad sense heritability.

Narrow sense ($h^2_n$) and broad sense ($h^2_b$) heritability were estimated from genetic variance components in $F_2$ population as shown in Table 16. Seed size was found highest values both for $h^2_n$ and $h^2_b$ (0.877 and 0.986, respectively). Pod length was also a character that showed high heritability ($h^2_n$ = 0.821 and $h^2_b$ = 0.940). The high values of these two characters indicated the importance of additive gene action. Yield per plant was also high in heritability, indicating high possibility for selecting out the plants in segregating population. Although the number of seeds per plant showed low heritability, the high estimates for the yield per plant would allow for selecting high yielding plants in $F_2$ population. The information from these heritability estimates together with the analysis for path coefficient of $F_2$ population which showed low negative direct effect of the number of seeds per plant (-0.0032) on seed size would allow the selection for plants that have high yield as well as a large seed size from $F_2$ segregates.

**Table 16. Narrow sense ($h^2_n$) and braod sense ($h^2_b$) heritability estimates of $F_2$ diallel crosses in mungbean.**

| | $F_2$ | |
|---|---|---|
| Characters | $h^2_n$ | $h^2_b$ |
| Seed size | 0.877 | 0.986 |
| No. pods/plant | 0.453 | 0.605 |
| No. seeds/pod | 0.619 | 0.678 |
| No. seeds/plant | 0.183 | 0.322 |
| Yield/plant | 0.760 | 0.760 |
| Pod length | 0.821 | 0.940 |
| Plant height | 0.554 | 0.730 |
| Biomass | 0 | 0 |
| Total dry matter | 0 | 0 |

The results from 16 experiments of mungbean as reviewed by Poehlman (1991) that broad sense heritability estimates for seed weight had the highest mean (81.1 %) followed by other yield and yield components. Especially seed yield had wide ranges for broad sense heritability from 8.6 (Empig *et al*., 1970) to 89.5 % (Paramasivan and Rajasekaran, 1980). Seed size had variable gene action in many experiments, but the additive gene effects were predominant in the inheritance of seed weight (Bhargava *et al*., 1966; Singh and Jain, 1971; Singh and Singh, 1971; Yohe and Poehlman, 1975; Wilson *et al*., 1985). Dominance effect of the gene(s) controlling seed weight was reported (Singh and Singh, 1971; Rao *et al*., 1984; Imrie *et al*., 1985). However, Malik *et al*. (1988) reported that small seed size was partially dominant over large seed size with gene action predominantly additive.

# Conclusion

Significant GCA effects for seed size were observed in both $F_1$ and $F_2$ generations, indicating different seed size of all six parents used. The large-seeded varieties had positive GCA effects while the small-seeded varieties showed negative effects.

The diallel analysis showed negative correlations of seed size and other yield components except the length of pod. SUT1 showed the highest GCA effect for seed size followed by KPS1 which indicated that these varieties were good genetic sources for increasing seed size. Moreover, the data of $F_2$ population showed significantly positive GCA for seed yield per plant and pod length of these two parents which indicated the possibility of simultaneous improving for these characters.

Although significant SCA effects were found in both $F_1$ and $F_2$ generations, the small values would indicate both positive and negative effects in these crosses. In another word, the seed size increased in one cross but decreased in another. It can be concluded from this study that the seed size character seemed to be complicated and low in heterosis but could be selected in the segregating population provided that appropriate crosses were used. Nevertheless, selection for yield components and seed yield per se may not be effective due to either low and negative SCA effects in most of these crosses. Among all varieties/lines used SUT1 appeared to be the best choice for increasing seed size and pod length as well as other yield components.

The narrow sense heritability observed on seed size, pod length, seeds per pod and plant height were important for additive gene action in $F_2$ generation, indicating these characters could be highly inherited to later generation.

Nevertheless, pods per plant, seeds per plant and yield per plant were found differing in gene action. Biomass and total dry matter showed the control by dominant gene action.

Based on this and other studies it can be concluded that seed size in mungbean is quantitatively inherited with additive gene action. Using large-seeded varieties in crossing would be effective for increasing seed size and rendering the opportunity for selecting high yielding plants from segregating population.

# References

Aher, R. P., Dahat, D. V., and Surve, P. P. (2001). Diallel analysis for yield contributing characters in mungbean. **Legume res.** 24 (2): 124-126.

Baker, R. J. (1978). Issues in diallel analysis. **Crop Sci.** 18: 533-536.

Bhargava, D. J., Johri, J. N., and Sharma, S. K., and Bhatt, B. N. (1966). Morphological and genetic variability in green gram. **Indian J. Genet. Plant Breed.** 26: 370-373.

Bhatnagar, P. S., and Singh, B. (1964). Heterosis in mungbean. **Indian J. Genet. and Plant Breed.** 24: 89-91.

Bhullar, K. S., Gill, K. S., and Khehra, A. S. (1979). Combining ability analysis over $F_1$-$F_5$ generations in diallel crosses of bread wheat**. Theor. Appl. Genet.** 55: 77-80.

Board, J. E., Kang M. S., and Harville, B. G. (1999). Path analyses of the yield formation process for late-planted soybean. **Agron. J.** 91: 128-135.

Bowman, D. T., and Jones, D. T. (1984). A diallel study of bract surface area/lint weight per boll ratio in cotton. **Crop Sci.** 24: 1137-1141.

Buerstmayr, H., Lemmens, M., Berlakovich, S., and Ruckenbauer, P. (1999). Combining ability of resistance to head blight caused by *Fusarium culmorum* (W. G. Smith) in the $F_1$ of a seven parent diallel of winter wheat (*Triticum aestivum* L.). **Euphytica** 110: 199-206.

Burow, M. D., and Coor, J. G. (1993). Diallel analysis and simulation. **User's guide.** Dep. of Agron., Univ. of Wisconsin, Madison, WI, USA.

Cho, Y., and Scott, R. A. (2000). Combining ability of seed vigor and seed yield in soybean. **Euphytica** 112: 145-150.

Choo, T. M., Reinbergs, E., and Jui, P. Y. (1988). Comparison of $F_2$ and $F_\infty$ diallel analyses in barley. **Genome** 30: 865-869.

Chung, J., Specht, J. E., Graef, G. L., and Livingston, M. J. (1997). QTL mapping for soybean seed weight using RAPD markers. In **Plant and Animal Genome V Conference**. Town and Country Hotel, San Diego, CA, January 12-16.

Cruz, C. D., and Regazzi, A. J. (1994). Biometric models applied to genetic improvement. Quoted in Franco, M. C., Cassini, S. T., Oliveira, V. R., Vieira, C., Tsai, S. M., and Cruz, C. D. (2001). Combining ability for nodulation in common bean (*Phaseolus vulgaris* L.) genotypes from Andean and Middle American gene pools. **Euphytica** 118: 265-270.

Cruz, C. D., and Vencovsky, R. (1989). Comparison of some dialectical analysis methods. Quoted in Franco, M. C., Cassini, S. T., Oliveira, V. R., Vieira, C., Tsai, S. M., and Cruz, C. D. (2001). Combining ability for nodulation in common bean (*Phaseolus vulgaris* L.) genotypes from Andean and Middle American gene pools. **Euphytica** 118: 265-270.

Egli, D. B., Leggett, J. E., and Wood, J. M. (1978). Influence of soybean seed size and position on the rate and duration of filling. **Agron. J.** 70: 127-130.

Empig, L. T., Lantican, R. M., and Escuro, P. B. (1970). Heritability estimates of quantitative characters in mungbean (*Phaseolus aureus* Roxb.). **Crop Sci**. 10: 240-241.

Franscisco, C. C. L., Regina, L. F. G., and Francisco, R. F. F. (2003). Genetic control of cowpea seed sizes. **Sci. Agri.** (*Piracicaba, Braz*.) [On-line serial] 60 (2). Available: Scientia Agricola

Fraser, J., Egli, D. B., and Leggett, J. E. (1982). Pod and seed development in soybean cultivars with differences in seed size. **Agron. J**. 74: 81-85.

Ghafoor, A., Zubair, M., Bakhsh, A., and Bashir, M. (1990). Heterosis among seven parents and their crosses in mungbean. **Pakistan J. Agri. Res.** 11: 169-173.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. **Aust. J. Biol. Sci.** 9: 463-493.

Gupta, M. P., and Singh, R. B. (1969). Variability and correlation studies in greengram (*Phaseolus aureus* Roxb.). **Indian J. Agri. Sci.** 39: 482-493.

Haussmann, B. I. G., Hess, D. E., Sissoko, I., Kayentao, M., Reddy, B. V. S., Welz, H. G., and H. H. Geiger. (2001). Diallel analysis of sooty stripe resistance in sorghum. **Euphytica** 122: 99-104.

Hayman, B. I. (1957). Interaction, heterosis, and diallel crosses. **Genetics** 42: 336-355.

Hayman, B. I. (1958). The theory and analysis of diallel crosses. **Genetics** 43: 63-85.

Imrie, B. C., Ahmed, Z. U., and Eerens, J. P. J. (1985). Heritability of seed weight in mungbean. **SABRAO J.** 17: 173-175.

Jinks, J. L. (1956). The $F_2$ and backcross generations from a set of diallel crosses. **Heredity** 10:1-30.

Joshi, S. N., and Kabaria, M. M. (1973). Interrelationship between yield and yield components in *Phaseolus aureus* Roxb. **Madras Agri. J**. 60: 1331-1334.

Kao, H. M., and McVetty, B. E. (1987). Quantitative genetic studies of yield, yield components, and phenological and agronomic characteristic in spring faba beans. **Genome** 29: 169-173.

Khan, I. A. (1985). Correlation and path coefficient analysis of yield components in mungbean (*Phaseolus aureus* Roxb.). **Botanical Bulletin Academia Sinica** 26: 13-20.

Khattak, G. S. S., Haq, M. A., Ashraf, M., and Srinives, P. (2001). Combining ability in mungbean (*Vigna radiatia* (L.) Wilczek) I. Agronomic traits. **Korean J. Crop Sci.** 46 (5): 420-423.

Khattak, G. S. S., Haq, M. A., Marwat, E. U. K., Ashraf, M., and Srinives, P. (2002 a). Heterosis for seed yield and yield components in mungbean (*Vigna radiata* (L.) Wilczek). **Science Asia** 28: 345-350.

Khattak, G. S. S., Asharaf, M., Haq, M. A., Mcneilly, T., and Rha, E. S. (2002b). Genetic basis of plant height and its degree of indetermination in mungbean (*Vigna radiata* (L.) Wilczek). **Hereditas** 137(1): 52-56.

Ko, M. S. (1979). Diallel analysis on the quantitative characters in mungbean (*Vigna radiata* (L.) Wilczek). **Journal Gyeongsang National University** 18: 27-52.

Lal, S., Gupta, S. N., and Tomer, Y. S. (1982). Line x tester analysis in mungbean. **Haryana Agri. Univ. J. Res.** 12: 438-443.

LeRoy, A. R., Cianzio, S. R., and Fehr, W. R. (1991a). Direct and indirect selection for small seed of soybean in temperate and tropical environment. **Crop Sci.** 697-699.

LeRoy, A. R., Fehr, W. R., and Cianzio, S. R. (1991b). Introgression of genes for small seed size from *Glycine soja* into *G. max*. **Crop Sci.** 31:693-397.

Malhotra, V. V., Singh, S., and Singh, K. B. (1974). Yield components in green gram (*Phaseolus aureus* Roxb.). **Indian J. Agri. Sci.** 44: 136-141.

Malik, B. P. S., Singh, V. P., Chaudhary, B. D., and Chowdhary, R. K. (1982). Path coefficients and selection indices in greengram. **Indian J. Agri. Sci**. 52: 288-291.

Malik, B. A., Khan, I. A., and Chaudhary, A. H. (1987). Heterosis in chickpea**. Pakistan J. Sci. Ind. Res.** 30: 396-398.

Malik, I. A., Ali, A., and Saleem, M. (1988). Incorporation of tolerance to mungbean yellow mosaic virus from local germplas into exotic large-seeded mungbean. Mungbean: **Proceedings of the Second International Symposium**. Asian Vegetable Research and Development Center, Shanhua, Taiwan.

Misra, R. C., Sahu, R. C., and Tripathy, D. (1970). A note on heterosis in green gram (*Phaseolus aureus* Roxb.). **Current Sci.** 39: 190-191.

Morgan, J. A., LeCain, D. R., and Wells, R. (1990).Semidwarfing genes concentrate photosynthetic machinery and effect leaf gas exchange of wheat, p. 84. Cited by Sexton, P. J., White, J. W., Boote, K. J. (1994). Yield-determining processes in relation to cultivar seed size of common bean. **Crop Sci.** 34: 84-91.

Paramasivan, J., and Rajasekaran, S. (1980). Genetic variability in greengram (*Vigna radiata* (L.) Wilczek). **Madras Agri. J**. 67: 421-424.

Parida, D., and Singh, D. P. (1984). Association, heritability and genetic advance in the $F_2$ generation of wide and varietal crosses of green gram**. Madras Agri. J.** 71: 351-356.

Patil, V. D., and Chopde, P. R. (1981). Combining ability analysis over environments in diallel crosses of linseed. **Theor. Appl. Genet.** 60: 339-343.

Poehlman, J. M. (1991). Genetics of quantitative characters. **The mungbean** (pp 195-222). New Delhi, Oxford & IBH Publishing.

Ramana, M. V., and Singh, D. P. (1987). Genetic divergence in mungbean. **Crop Improvement** 14: 23-27.

Reddy, P. R. R., and Sreeramulu, C. (1982). Heterosis and combining ability for yield and its components in greengram (*Vigna radiata* (L.) Wilczek). **Genetica Agraria** 36: 297-308.

Rao, S. S., Singh, S. P., and Rao, S. K. (1984). Estimation of additive, dominance, digenic epistatic interaction effects for yield and its components in mungbean (*Vigna radiata* (L.) Wilczek). **Legume Res.** 7: 6-12.

Sekhar, M. R., Reddy, K. R., and Reddy, C. R. (1994). Heterosis for yield and yield components in mungbean (*Vigna radiata* (L.) Wilczek). **Indian J. Genet.** 54: 1-5.

Shinde, N. V., and Deshmukh, R. B. (1989). Heterosis in urdbean. **Indian J. Pulses Res.** 2: 119-124.

Singh, K. B., and Jain, R. P. (1970). Heterosis in mungbean. **Indian J. Genet. Plant Breed.** 30: 251-260.

Singh, K. B., and Jain, R. P. (1971). Combining ability for pod length and seed size in mungbean. **Indian J. Genet. Plant Breed.** 31: 145-148.

Singh, K. B., and Malhotra, R. S. (1970). Estimates of genetic and environmental variability in mungbean (*Phaseolus aureus* Roxb.). **Madras Agri. J.** 57: 155-159.

Singh, S. P., Singh, H. B., Mishra, S. N., and Singh, A. B. (1968). Genotypic and phenotypic correlations among some quantitative characters in mungbean. **Madras Agri. J.** 55: 233-237.

Singh, T. P., and Singh, K. B. (1971). Mode of inheritance and gene action for yield and its components in *Phaseolus aureus*. **Can. J. Genet. Cytol.** 14: 517-525.

Swindell, R. E., and Poehlman, J. M. (1976). Heterosis in the mungbean (*Vigna radiata* (L.). Wilczek). **Tropical Agri.** 53: 25-30.

Upadhaya, L. P., Singh, R. B., and Agarwal, R. K. (1980). Character associations in greengram populations of different maturity groups. **Indian J. Agri. Sci.** 50: 473-476.

Verhalen, L. M., and Murray, J. C. (1969). A diallel analysis of several fiber property traits in upland cotton (*Gossypium hirsutum* L.) II. **Crop Sci.** 9: 311-315.

White, T. G. (1966). Diallel analysis of quantitatively inherited characters in *Gossypium hirsutum* L. **Crop Sci.** 6: 253-255.

Wilson, D., Mercy, S. T., and Nayar, N. K. (1985). Combining ability in greengram. **Indian J. Agri. Sci.** 55: 665-670.

Yates,____. (1974). Quoted in Gilbert, N. E. G. (1958). Diallel cross in plant breeding. ______. 477-492.

Yohe, J. M., and Poehlman, J. M. (1975). Regression, correlations, and combining ability in mungbeans (*Vigna radiata* (L.) Wilczek). **Tropical Agri.** 52: 343-352.

# APPENDIX

**Table 1. Mean of characters in variety/line in $F_1$ population.**

| Variety/line | 100-seed weight (g) | No. pods/plant | No. seeds/pod | No. seeds/plant | Yield/Plant (g) |
|---|---|---|---|---|---|
| SUT1 | 7.96 | 26 | 5.60 | 143 | 5.29 |
| KPS1 | 6.83 | 15 | 8.97 | 134 | 8.76 |
| V3273 | 4.65 | 24 | 8.69 | 207 | 9.16 |
| VC1173A | 3.57 | 41.33 | 8.82 | 365 | 12.14 |
| VC1210A | 5.76 | 43.33 | 7.63 | 332 | 18.43 |
| V4718 | 3.34 | 30.33 | 7.01 | 215 | 7.82 |

Table 2. Mean of characters in variety/line in $F_2$ population.

| Variety/line | 100-seed weight (g) | Pods/plant | Seeds/pod | Seeds/plant | Yield/ plant (g) | Pod length (cm) | Biomass (g) | Total dry matter (g) | Plant height (cm) |
|---|---|---|---|---|---|---|---|---|---|
| SUT1 | 6.70 | 28.28 | 8.575 | 157 | 9.948 | 9.21 | 136.48 | 29.488 | 62.875 |
| KPS1 | 6.36 | 23.80 | 9.550 | 178 | 11.168 | 8.74 | 154.37 | 36.748 | 65.500 |
| V3273 | 4.03 | 35.11 | 10.062 | 278 | 10.885 | 7.31 | 145.90 | 43.240 | 79.300 |
| VC1173A | 3.18 | 36.40 | 10.975 | 300 | 9.382 | 6.84 | 147.08 | 35.428 | 68.000 |
| VC1210A | 5.24 | 29.40 | 10.125 | 218 | 11.278 | 8.61 | 144.12 | 37.748 | 72.200 |
| V4718 | 3.72 | 12.60 | 9.625 | 80 | 2.772 | 7.43 | 118.02 | 18.590 | 74.875 |

**Table 3. Approximate analysis of nutrients in 100 g of edible portion of mungbean.**

| Component | Amount |
|---|---|
| Protein (%) | 25.98 |
| Fat (%) | 1.30 |
| Ash (%) | 3.80 |
| Crude fiber (%) | 4.79 |
| Carbohydrate (%) | 64.12 |
| Vitamin A (IU) | 70 – 130 |
| Vitamin B1 (mg/100g) | 0.52 – 0.66 |
| Vitamin B2 (mg/100g) | 0.29 – 0.22 |
| Niacin (mg/100g) | 2.4 – 3.1 |
| Vitamin C (mg/100g) | 0 – 10 |
| Potassium (100 mg/100g) | 850 – 1450 |
| Sodium (mg/100g) | 30 – 170 |
| Magnesium (mg/100g) | 65 – 125 |
| Phosphorus (mg/100g) | 280 – 580 |
| Iron (mg/100g) | 5.43 – 6.42 |
| Calcium (mg/100g) | 80 – 330 |

Source : AVRDC

www.gov.lk/Agriculture/Agridept/Techinformations/Glegumes/Mung.htm

**Table 4. Soil characteristics of the experimental plot.**

| Nutrient elements | Concentration | Level |
|---|---|---|
| Phosphorus | 26 ppm | High |
| Potassium | 140 ppm | Very high |
| Calcium | 960 ppm | High |

Remark : Soil pH 6.4.

Soil salinity = 0.30 mmho at 25°C (normal).

# BIOGRAPHY

Miss Pantipa Na Chiangmai was born on September 2, 1976 in Chiang Mai province, Thailand. She received a bachelor degree in agricultural science from Agronomy Department, Faculty of Agriculture, Chiang Mai University in 1997 and a Master's degree in plant breeding from the same university in 1999 which she was awarded the fellowship from the National Science and Technology Development Agency (NSTDA).

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