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PLANT TYPE, YIELD, AND COMPONENTS OF YIELD IN MUNGBEANS (*VIGNA RADIATA* (L.) WILCZEK)

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and hereby certify that in their opinion it is worthy of acceptance.

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PLANT TYPE, YIELD, AND COMPONENTS OF YIELD IN MUNGBEANS (*VIGNA RADIATA* (L.) WILCZEK)

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ABSTRACT

For the food grain legume (*Vigna radiata* (L.) Wilczek) little is known about the inheritance of characteristics which determine plant type or about the inherent potential for yield. The objectives of this study were: (1) to obtain estimates of the predominate types of combining ability for each of ten characters studied, (2) to obtain heritability estimates for the ten agronomic characters investigated, (3) to determine the relationship between yield and the components of yield, and (4) to investigate the extent of heterosis present in crosses among the varieties of mungbeans studied. The characters studied were yield per plant, number of pods per plant, number of seeds per pod, 1000-seed weight, number of days to first flower, number of days to first ripe pod, plant height, branch length, virus score, and mildew score. Five varieties selected for their diverse plant characteristics and broad genetic divergence were used as parents in this study. The five parents and the

respective F_1's from crosses among them were planted in a randomized complete block design with five replications at the University of Missouri Bradford Research Farm, Columbia, in 1971. In 1972, three parents and their respective F_1 and F_2 populations were grown. The data were subjected to a diallel analysis as described by Griffing (1956).

Yield and the components of yield, number of pods per plant, number of seeds per pod, and 1000-seed weight, are highly correlated with the plant type characters, plant height and branch length. The high yielding variety in this test was a prostrate plant type, where many of the pods lay close to or on the ground. Segregants have been identified which will be useful in developing erect plant types that will hold the pods up off the ground as well as be adaptable to mechanical harvesting.

From the diallel cross analyses, the simple phenotypic correlations, and the high narrow sense heritability estimates, it was shown that number of pods per plant had the greatest effect on yield, even though number of pods per plant was the yield component most affected by environment.

A large portion of the total genetic variation associated with the yield components was the result of additive gene action. Specific combining ability effects were significant for part of the characters studied but were less important overall than the general combining ability effects.

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CHAPTER I

INTRODUCTION

The food needs of the world's rapidly growing population are not being adequately met. Most of the developing countries are losing the capacity to feed themselves because per capita food production fails to keep pace with population growth. This failure to meet basic dietary needs results in serious nutritional problems. In view of the impending worldwide food shortages, plant breeders need to be concerned with the development of improved genotypes which will function in widely varied environments.

Variability within the plant populations is the basis upon which plant improvement has been made. It is necessary for the plant breeder to procure, assess, and preserve valuable germ plasm for future incorporation into new crop cultivars. Sources of adaptation or resistance to environmental factors may include wild progenitors, primitive populations, land varieties, and advanced strains from breeding nurseries.

Among the food grain legumes little is known about the inherent potential for high yield. The mungbean (*Vigna*

radiata L. Wilczek)*, a widely grown edible legume, is a valuable potential contributor to the world food pool. Research on this species is scant and varietal development is just beginning to receive attention. Hybridization studies have indicated that heterosis is present among some mungbean crosses. It is important then, to obtain information on yield potentials from research on combining ability, inheritance of the components of yield, plant size, and plant shape and hybrid vigor. It is important to breed ideal plant types with high potential for the components of yield such as pod size, seed size, and seeds per pod.

Therefore, in order to make progress in selecting for a complex character such as yielding ability in mungbeans, the breeder must know the portion of the total variation observed in segregating generations that is due to the genetic composition, and the type of gene action contributing predominately to the character. This information is of particular importance to the breeder of self pollinating plants since only additive gene action and epistatic effects which behave in an additive manner can be utilized. Such information for each of the yield components, as well as the relationships between these

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*The scientific name of mungbean has changed several times. Previous references have used Phaseolus aureus Roxb. The reference to the new name is 'Verdcourt, G., 1970, Studies on the Leguminosae-Papilionoideae for the "Flora of Tropical East Africa": III, Kew Bull. 24:556-558.'

components and yield, would help in determining the type of selection program to follow for obtaining higher yielding cultivars of mungbeans.

The primary objectives of this study were: (1) to obtain estimates of the predominate types of combining ability for each of ten characters studied, (2) to obtain heritability estimates for the ten agronomic characters investigated, (3) to determine the relationship between yield and the components of yield, and (4) to investigate the extent of heterosis present in crosses among the varieties of mungbean selected.

CHAPTER II

LITERATURE REVIEW

Combining ability, heritability, correlation studies related to yield and plant type, and heterosis have been investigated extensively for many crops. This review will be concerned with mungbeans and closely related self pollinated crops.

Genetic Variability and Combining Ability

Genetic improvement of the mungbean has been limited mostly to evaluation and selection within local strains. This experience has led to a wide spread belief that genetic variability in this species is relatively narrow. Nowhere has there been a vigorous hybridization program utilizing broad based germ plasm on a scale comparable with that which has been used in the cereal grains.

The first step in any breeding program is to survey the genetic resources available. Banks (1958) evaluated 138 mungbean strains and reported wide variability for growth habit, plant height, number of seeds per pod, seed yield, seed size, and other taxonomic characters. Yohe and Poehlman (1972) grew three hundred and twenty-one strains of mungbeans, originating from 18 American, Asian, African, and Middle Eastern countries, at Columbia,

Missouri, and evaluated them for yield, days to first ripe pod, plant height, length of first branch, pods per plant, number of seeds per pod, 1000-seed weight, virus resistance, mildew resistance, percent protein, percent lysine, and percent methionine. They reported a wide range in genetic variability for each character studied.

In recent years numerous investigations have been conducted to assess the relative importance of the various types of gene action contributing to variability in quantitative characters in self-pollinated crops. These studies have employed both diallel cross analyses and analyses of early segregating generations from crosses among pure lines. In general, additive genetic effects have been shown to be of major importance in quantitative character expression, although non-additive effects have also been found to be of importance in some instances. Implications and limitations of investigations of this type have been discussed in relation to breeding methodology by Matzinger (1963).

According to Lush (1948), Schmidt, in 1919, introduced a diallel crossing system in which each of a group of males was crossed to each of a group of females. This type of diallel crossing system compares to the procedure used in plants where crosses are made in all possible combinations among a group of parents. The concepts of general and specific combining ability were precisely formalized by Sprague and Tatum (1942). 'General combining

ability' was defined as the average performance of a line in a series of hybrid combinations, while 'specific combining ability' was used for those cases in which certain hybrid combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Genetically, general combining ability is associated with genes which are additive in their effects; specific combining ability is attributed primarily to deviations from the additive scheme due to nonadditive genetic effects caused by dominance, overdominance, epistasis, and genotype x environment interaction (Rojas and Sprague, 1952). In general, lines selected for high general combining ability are expected to give desirable specific combinations. Considerable interest has been shown in recent years in the analysis of diallel crosses for evaluating parental lines for their combining ability.

The technique of diallel cross analysis, developed by Jinks and Hayman (1953), Hayman (1954, 1957, 1958, 1960), Griffing (1956), Allard (1956), Kempthorne (1956), and others, makes use of a set of parents crossed in all possible combinations for rapidly securing overall genetic information. This technique makes it possible to test the independence of genotypic effects from environmental effects and provides information on reciprocal cross effects, the estimates of general and specific combining ability effects, the magnitude of additive gene action, and the dominance and interaction effects of genes. Applied to

problems of breeding for yield in wheat, sorghum, cotton, and other crops, the diallel technique has yielded much useful information although subject to certain assumptions and limitations. An important practical difficulty is development of a sound basis for selecting from a germ plasm collection the restricted number of parents which one can put into the diallel analysis.

Griffing (1956) listed four methods of diallel crosses. The type of analysis depends on the presence or absence of the parental inbreds and/or the reciprocal F_1's. The four possible methods are: (1) parents, one set of F_1's and reciprocal F_1's are included (P^2 combinations); (2) parents, and one set of F_1's are included (1/2 P(P+1) combinations); (3) reciprocal F_1's are included, but not the parents (P(P-1) combinations); and (4) one set of F_1's only is included (1/2 P(P-1) combinations). In addition Griffing (1956) pointed out that the interpretation of these four methods depends on two sampling assumptions. The Model I assumption is that the parental genotypes are deliberately chosen and constitute the entire population about which inferences are to be made. In Model II, the parental genotypes are assumed to be a random sample from some population about which inferences are to be made. Parental genotypes are usually homozygous lines, but they can also be individual clones, open-pollinated varieties, or other genetic entities. Griffing (1950) suggested that parental and F_1 data have distinct advantages over data from segregating generations in studying quantitative genetic systems because they are

not confounded by segregation and linkage. Therefore, few individuals are necessary for efficient estimation of certain genetic parameters.

Allard (1956) applied the method of Jinks and Hayman (1953) to diallel cross data delineating lima bean size and used the genetic information obtained in identifying the parents whose hybrids are likely to give the maximum response to selection.

Leffel and Weiss (1958) in a 10-parent diallel cross with soybeans, reported that three methods of statistical analyses were similar in detecting lines exhibiting unexpected performance in the F_1 generation but gave different estimates on which were based the interpretations of parental-F_1 relationships. They concluded that the diallel experimental design is useful in that the parental and F_1 performance may be used to predict potentialities of crosses in later generations and is also helpful in understanding the genetical explanation of hybrid performance and its role in the selection of an efficient breeding method.

A diallel analysis of seven economic characters in snapbeans by Dickson (1967) indicated that additive genetic variance was predominant for number of seeds per plant, number of seeds in best of five pods, length of pod, number of pods per plant, and the number of days to flowering. Pod number was also influenced by dominance and by recessive genes contributing to large pod number.

Dhaliwal and Singh (1970) made all possible crosses, excluding reciprocals, with six pure breeding lines of black gram (Phaseolus mungo L.) and observed pod and cluster number per plant. General combining ability was significant for both characters but specific combining ability was not significant. High pod and high cluster number per plant were recessive and additive gene effects with partial dominance were observed.

Singh and Jain (1971), using a 6 parent diallel cross in mungbeans, studied general and specific combining ability effects and gene action for pod length and seed size. Their work indicated that general combining ability was important for pod length but both general combining ability and specific combining ability were important for seed size. A graphical analysis of the data (Hayman, 1954) suggested additive gene effects with some overdominance for pod length and seed size.

Components of Yield

Yield is a complex heritable character influenced by many morphological and physiological characteristics of the plant interacting with the environment. Grafius (1959) suggested that yield was an artifact and, consequently, there could be no genes for yield. Therefore, there could be no dominance effects, no overdominance effects, no additive effects, and in turn no heritability of yield. Under this assumption yield was the end result of several

components that were in turn quantitatively inherited.

Working with spring and winter wheats, Quisenberry (1928) measured yield and its components, number of heads per unit area, number of kernels per head, and weight per 1,000 kernels. Correlations between yield and the three components were significant, but correlations between heads per unit area and weight of 1,000 kernels and between number of heads per unit area and kernels per head, were not significant. By the use of partial correlation coefficients he determined that the number of heads per unit area had the greatest influence on yield and weight of 1000 kernels had the least. Multiple correlation coefficients between yield and its three components ranged from 0.96 to 0.98.

Grafius (1956) applied a geometric interpretation to the relationships among yield components in oats. He postulated that the three components, number of panicles per unit area, number of kernels per panicle, and kernel weight, could be thought of as the edges of a rectangular parallelpiped with yield represented by volume. He theorized that a variety might be improved most effectively by lengthening the short edge of the rectangle representing the components of yield.

Singh and Mehndiratta (1970) reported that three yield components, pods per plant, seed per pod, and 100-seed weight, had a large and direct effect on yield in cowpeas (*Vigna siensis*). They used the path coefficient analysis

technique, which has been useful in finding out direct and indirect causes of associations and allowed a detailed examination of specific forces acting to produce a given genetic correlation and to measure the relative importance of each causal factor. They also used correlation analyses in conjunction with partial regression studies to provide information about the dependence of yield on correlated characters. In their study, pods per plant, seeds per pod, and 100-seed weight had a large and direct effect on yield. The multiple regression analysis suggested that pods per plant, seeds per pod, and 100-seed weight are the important yield components and together accounted for 68 percent of the variation in yield.

In a study of three crosses with field beans (Phaseolus vulgaris), Coyne (1968) calculated simple and partial correlation coefficients between total seed yield and the yield components, number of pods per plant, number of seeds per pod, and mean seed weight, and correlations among pairs of these yield components in parental and derived generations. Partial correlations were high between total seed yield and each yield component. The majority of the partial correlation coefficients among the yield components were low. This suggested that it should be possible to select for an increased value of one yield component without reducing the value of the other components.

Adams (1967) explained that negative correlations among yield components were wide spread among the major

crop plants, particularly under various kinds of environmental stress. He believed that the negative correlations may be developmental rather than genetic *per se* and were postulated to be caused by genetically independent components, developing in a sequential pattern that was free to vary in response to either 1) a limited constant input of metabolites, or 2) an oscillary input such that the input was limited at a critical stage in the development sequence.

Singh and Mehndiratta (1969) indicated that measurements of phenotypic, genotypic, and environmental correlations between yield and other characters in cowpea have been of great importance in their work. In a study of forty lines, they concluded that pods per plant had the highest genetic coefficient of variation (52.5 percent). Grain yield was positively correlated to number of branches, number of pods, seeds per pod, and 100-seed weight.

According to Singh and Malhotra (1970) genotypic correlation coefficients were greater than phenotypic or environmental correlation coefficients in varieties of mungbeans (*Phaseolus aureus*). Seed yield was positively associated with branches per plant, pod length, seeds per pod, and seed size. A multiple regression analysis indicated that seed size, seeds per pod, and pods per plant were the most important characters determining yield in mungbeans. A path coefficient analysis indicated that pods per plant, seeds per pod, and seed size influenced the seed

yield if other yield components were held constant. As seed size increased, number pods per plant, and number seeds per pod decreased resulting in lower yield.

Heritability and Genetic Advance

Heritability is the proportion of total variation in a population caused by genetic factors. Lush (1948) estimated heritability in two ways: (1) in the broad sense, in which the whole genotype functions as a unit and was contrasted with the environmental effect, and (2) in the narrow sense, in which the heritability included only the average effects of genes transmitted additively from parent to progeny. Information on heritability estimates in the narrow sense is of value to the breeder as a measure of efficiency in selection and as an index of transmissibility in segregating populations.

Dudley and Moll (1969) defined broad sense heritability as the ratio of total genetic variance to phenotypic variance, and narrow sense heritability as the ratio of additive genetic variance to phenotypic variance. Phenotypic variance was the total variance among phenotypes when grown over a range of environments. Genetic variance was the part of the phenotypic variance which can be attributed to genotypic differences among phenotypes. The genetic variance may then be further subdivided into additive, dominance, and epistatic genetic variance.

Warner (1952) reviewed the methods for estimating

degree of heritability in crop plants. The technique may be grouped into three categories based on: (1) parent-offspring regression, (2) variance components from analysis of variance, and (3) approximations of nonheritable variance from genetically uniform populations.

In self-pollinating species such as the mungbean, the plant breeder is primarily interested in narrow sense heritability estimates which measure additive gene action since that is the only portion of the total genetic variability that can be fixed in succeeding generations. Under this definition heritability may be considered as an index of transmissibility by using parent-offspring regression, or F_2 and back cross data, to estimate the additive genetic variance. Petr and Frey (1966) studied six quantitatively inherited traits in the F_1 and F_2 generations of oats and calculated broadsense heritabilities. Heritability percentages were 33, 53, 54, 61, 74, and 87 for number of panicles per plant, grain yield, panicle length, plant height, number of spikelets per panicle, and heading date, respectively. The heritability percentages and high level of dominance for yield and panicles per plant in the F_1 indicated that selection for those attributes should be delayed until late generations, whereas selection for plant height, panicle length, number of spikelets, and heading date should be feasible in early generations.

In investigating the heritability and expected genetic advance in soybeans, Anand and Torie (1963)

determined that heritability estimates for seed yield, pods per plant, and seeds per pod were low. The 100-seed weight was high in heritability, but was not correlated with seed yield. These results would indicate that selection for seed yield in early generations would be difficult. Estimates of heritability generally were high for lodging resistance, height, date of flowering, date of fruiting, and maturity.

Coyne (1968) found that heritability estimates were low for total seed yield and for each of the three yield components in field bean (Phaseolus vulgaris). No yield improvement was realized in the F_3 by selecting the top five percent of the F_2 for total yield, or by selecting separately for each of the yield components.

Narrow sense heritability values, according to Sandha and Chandra (1969), were found to be high for number of primary and secondary branches and for seed setting percent, moderate for length of longest branch, and low for the other characteristics studied. High genetic gain was obtained for number of branches but not for seed setting percentage or for length of branch in chick pea (Cicer aritinum).

Singh and Mehndiratta (1969) studied 40 cowpea (Vigna siensis) lines and reported that heritability was high for 100-seed weight, days to flowering, pod length, and days to maturity. Expected genetic advance was large for number of branches, 100-seed weight, pod number, pod

length, and yield. Seed weight had the highest heritability and highest expected genetic advance.

Singh and Malhotra (1970) studied genetic and environmental variability in a collection of 75 indigenous and exotic strains of mungbean. They found that the 75 strains appeared to differ in eight quantitative characters contributing to yield. They concluded that selection would be effective when based on 1000-seed weight, which had high genetic variability and expected genetic advance. Genetic advance was observed to be high for pod number, cluster number, and seed yield, also, but these characters had low heritability estimates.

Bhargava et al. (1966) partitioned the observed variability in mungbean into its genetic components in order to estimate heritability. Significant morphological differences were observed for all characters among the varieties studied. Plant height, cluster per plant, pods per plant, and yield per plant showed a large genotypic coefficient of variation while a small amount of variation was observed for characters like branches per plant, pod length, seeds per pod, and 100-seed weight. Most of the characters had high heritability but pod length and seeds per pod gave low estimates.

Empig, et al. (1970) calculated broad sense heritability estimates for nine quantitative characters in the F_2 of five crosses of mungbean strains. Over the five crosses, days to maturity had a heritability estimate of

71.2 percent, highest for the nine characters studied. The lowest was for seed yield with a mean estimate of heritability of 8.6 percent. In the F_3, broad sense heritability estimates for seed yield and its components, pods per plant, seeds per pod, seed weight, and seeds per plant, were calculated by variance component analysis in one of the five crosses. Seed weight had the highest estimate of heritability, 85 percent, whereas seed per pod was 49 percent, seed yield, 47 percent, pods per plant, 31 percent, and the number of seeds per plant had the lowest, 26 percent. Based on F_2 data, highest expected genetic progress could be obtained for maturity (37 percent of the mean) and was obtainable by selecting the top five percent of the F_2 progenies. Expected genetic advance for seed yield was only five percent.

Growth Habit

At present many of the high yielding mungbean varieties are prostrate, with spreading growth habits which when mature becomes a bushy, tangled mass of plant tissue where many of the pods lay close to or on the ground. This type of growth also creates a tight leaf canopy that doesn't allow air exchange and is inefficient in utilizing sunlight. For maximizing yields, the breeder is concerned about developing an erect plant type, which will hold the pods up off of the ground in a dense population and still have an open leaf canopy for air exchange and light

utilization. The erect plant type would also lend itself to mechanical harvesting whereas the prostrate type doesn't.

Emerson (1916) described two distinct types of common bean with respect to habit of growth, determinate and indeterminate. The determinate type is called the bush bean and the indeterminate type is called the pole bean. The very tall and very dwarf beans (pole and bush) differ by a single, dominant genetic factor for habit of growth. Evidence was presented to show that plant height in beans was influenced by genetic factors for number of internodes and internode length which were independent of habit of growth. He suggested that number of internodes and length of internodes were quantitatively inherited.

In 1915, Norton reported that growth habit in common bean was determined by three factors, A, L, and T, which may be present in any combination, giving rise to varying habits of growth. A, the presence of axial infloresence, permitted an indefinite growth of the main stem and main branches while a terminal infloresence caused a definite growth. The length of the axis, symbolized by L, was an important factor controlling plant habit and was probably governed by a series of two or more factors for length, L_1, L_2, etc. These factors behaved after the fashion of Emersons (1916) hypothesis for the inheritance of quantitative characters. The climbing habit was due to factor T, which was a factor for circumnutation. The cause of

various degrees of the climbing habit had not been determined. The contorted stems of the erect bush forms were probably caused by the factor T.

Camacho, et al. (1968) studied the relationship of growth habit and yield components in beans (Phaseolus vulgaris L.). Selections were made for tall and dwarf climbing habit and for bush habit from progenies of crosses between climbing types and bush types. In three of four crosses, the F_5 and F_6 selections which were climbing types had higher seed yields than those of the bush type, the difference was due to the seed yield per plant. The bush type selections produced more pods per plant than the bush type parents, but resulted in higher yields in only one cross. Selections among the climbing types had lower average yields than the climbing type parents which resulted from fewer pods per plant and fewer seeds per pod.

Frazier, et al. (1968) in a series of pole x bush bean crosses, reported that the determinate growth habit was conditioned primarily by a single recessive gene. In their work segregation for the upright bush type, as compared to an open, sprawling growth type, was much more difficult to obtain. It was apparent that bush habit was conditioned by many genes. The data on recovery of "upright" bush habit indicated that at least three major recessive genes and/or perhaps many minor genes may be involved. The range of growth habit, height, internode length, internode number, and number of side branches,

all varied over a wide range. It was difficult to establish clear cut classifications of "true bush" versus prostrate or trailing types. It was easy to distinguish between determinate versus indeterminate growth habit and to eliminate three-fourths of the segregating progeny in the early stages of growth.

In an analysis of gene action involved in the expression of growth habit and of morphological characters related to growth, Davis and Frazier (1966) reported on a population derived from all the possible crosses among two true bush varieties and two Blue Lake bush lines (derived from recurrent backcrossing to FM-1 Blue Lake pole bean). The true bush varieties appeared to contain more of the recessive alleles for upright habit, plant height, number of central stem internodes, and number of branches than did the Blue Lake bush lines. The role of recessive genes in conditioning stiff, upright bush habit was considered of major importance. The net effect of genes conditioning the expression of habit, height of pod attachment, and number of internodes was largely additive. In the expression of plant height, the net effect was largely non-additive with marked heterosis being noted.

Bulah and Aristarhova (1970) made a mathematical analysis of 18 characters in ten soybean cultivars belonging to different ecotypes grown under different photoperiods and other conditions. Variance was least for time of maturity, breadth of pod, seed size, height, and stem

diameter, and greatest for number of pods and seeds per plant. The angle of branch insertion, stem diameter, and pod length, were determined almost exclusively by the genotype.

Pathak and Singh (1963) reported on the inheritance of growth habit in mungbeans. They observed two common types of growth habit, semierect and semispreading, which could be further classified as twining and nontwining. When they crossed a seimspreading-twining habit x erect-nontwining type the F_1 generation contained only spreading, nontwining plants. There was a 3:1 segregation ratio in the F_2 for both spreading vs. erect habit and nontwining vs. twining habit, indicating a single factor difference for each character. When both factors were considered together, they obtained a 9:3:3:1 dihybrid ratio indicating that the two characters segregated independently.

Heterosis

Increased vigor has been observed in the 18th and 19th century by early hybridizers, but the concept of heterosis was not definitely formulated until the early 1900's by Shull. Heterosis is a genetic expression of the beneficial effects of hybridization. For heterosis to be practically utilized there must be sufficient increase in yield, quality, and uniformity, or other attributes, of the plant to offset the cost involved in producing the parent lines and the hybrid seed.

Ashton (1946) summarizing the evidence for heterosis in wheat, oats, barley, sorghum, rice, cotton, tobacco, tomato, eggplant and soybean, and reported heterosis relative to the midparent was wide spread in self-pollinated plants. Each crop exhibited a heterotic response for some character, although the expression of heterosis varied depending upon the specific parents crossed. East (1936), Smith (1944), and Whaley (1944) have presented extensive reviews of the earlier literature on heterosis. Matzinger (1963) has given an excellent discussion of the situations in which hybrids might be used to distinct advantage over pure lines in self-pollinated crop species.

Gritton (1969) crossed eight different varieties of peas (Pisum sativum L.) in all possible combinations and examined the parents and F_1's for dry seed weight. The F_1 plants exceeded the better parents by 26 percent in one location and by 37 percent in another. In a subsequent experiment the corresponding increases in seed weight over the parents were 17 percent and 21 percent. Thirteen F_1 hybrids exhibited a large amount of heterosis for both locations in both years. Five of the hybrids exceeded the highest yielding variety and eleven hybrids exceeded the second highest yielding variety. The F_2 yield of the hybrid exceeded that of the higher yielding parent in all but one of the 13 crosses.

Leng (1954) considered heterosis to have been expressed in any case in which the F_1 hybrid between two

inbred lines exceeded the higher parental line (high parent) for a particular character. He studied the effects of heterosis on grain yield and its components in corn, number of ears per plant, weight of grain per ear, kernel weight, number of kernels, number of rows, number of kernels per row, and grain yield. The hybrid exceeded the high parent by highly significant margins for grain yield, weight of grain per ear, number of kernels per ear, and number of kernels per row. The concept of the F_1 hybrid exceeding the higher parental line has been referred to as heterobeltiosis.

Probably the first record of heterosis in intraspecific crosses of mungbean (Phaseolus aureus Roxb.) was reported by Bhatnager (1964). He crossed three 'pure line' strains with one 'pure line' recurrent parent and reported that the F_1 exceeded the midparent in the three crosses for plant height, number of branches per plant, number of pods per plant, length of pods, number of seeds per pod, weight of 100 seed, number of mature pods per plant, and total seed yield per plant.

Misra (1970) observed the heterotic effects in the F_1 from a cross between two mungbean varieties in six of eight characters studied. The grain yield of the hybrid exceeded the midparent and the highparent. Singh and Jain (1970), in a 7 x 7 diallel cross, reported hybrid vigor exceeding the midparent for grain yield, pod length, branch number, days to flowering, and plant height in

mungbean. He noted a decrease in seed size below the mid-parent. Singh and Malhotra (1970) indicated that the F_1 plants of mungbean derived from a diallel cross involving seven varieties exceeded their respective parents in seed yield, pod length, and branch length. The heterotic effects found in the F_1 were maintained in the F_2 in some of the crosses.

CHAPTER III

MATERIALS AND METHODS

Selection of Parents

Five varieties of mungbean (*Vigna radiata*, L. Wilczek) were used as parental lines in a five parent diallel experiment in 1971. The parental varieties were selected on the basis of their diverse plant characteristics and were assumed to have broad genetic divergence. The parental varieties, their origin, and data on their characteristics are given in Table 1. Variety M101 was chosen for large seed size, prostrate growth habit, and excellent vigor. Variety M304 was chosen for a large number of seeds per pod and erect, bushy growth habit. Variety M317 was chosen for erect bushy growth habit, good podding habit, and good vigor. Variety M299 was chosen for small seed size, early flowering, and dwarf erect growth habit. M277 was chosen for erect growth habit. Selection of these varieties for this study was made during the summer of 1970, from visual observations in the field at Columbia before quantitative data were available from which specific comparisons could be made. The data in Table 1 are based on subsequent observations made during the years of 1970, 1971, and 1972. Three of the varieties, M101, M304, and M317, were also used in a three parent diallel experiment

Table 1. Mungbean parental varieties used in a diallel analysis study. Data are a three year average (1970, 1971, 1972) in the field at Columbia, Missouri.

USDA P.I. No.	Mo. Acc. No.	Origin	Yield kg/ha	Pods per plant	Seeds per pod	1000 seed weight g	Days to first flower	Days to first ripe pod	Plant height cm	Length first branch cm	Virus score (0to100)	Mildew score (1to5)
271401	M101	India	1938	103	12.3	73	52	72	50	55	0.7	2.6
273487	M304	Korea	1150	76	13.0	56	51	72	59	46	15.7	4.1
298915	M317	China	1712	109	13.7	64	53	75	70	62	20.3	3.9
271405	M299	India	665	67	10.0	37	42	58	39	30	8.3	5.0
246130	M277	Madagascar	471	39	9.8	43	61	81	66	52	43.0	3.8

in 1972.

Crossing Procedure

During the winter of 1970-71 all possible combinations of crosses were made in the greenhouse. Seed for reciprocal crosses were not kept separate. The method of crossing was a variation of the method developed by Buishland (1956) and Boling, Sander, and Matlock (1961) The flower bud was emasculated in the evening before dehiscence by taking the flower between the thumb and forefinger of the left hand and carefully removing the standard, wing and keel petals with a pair of forceps, care being taken to not disturb the pedicel attachment to the peduncle. As soon as the keel petals have been removed, the stamens can be removed. Pollination was accomplished early the next morning by removing a pollen bearing stigma from a blooming flower and brushing it gently across the stigma of the emasculated flower.

Experimental Procedure

Five Parent Diallel

Forty seeds from each of the five parents and the ten F_1 single crosses were planted in plates of 12 peat pots (4 cm x 4 cm) in the greenhouse on June 8, 1971. Prior to planting seeds were inoculated with 'EL' commercial culture inoculent. The seedlings were transplanted to the field June 16th, on the University of Missouri, Department

of Agronomy, Bradford Experimental Farm, Columbia, Missouri, in a randomized complete block design with five replications. A plot consisted of eight seedlings of each entry in a row 3.5 m in length with 45 cm between plants within the row. The spacing between rows was 1.5 m. Miscellaneous strains were transplanted into the border rows of the blocks to equalize competition effects. Where necessary, dead seedlings were replaced with healthy plants on June 18th, in order to maintain uniform stands. The plots were fertilized with a 12-12-12 commercial fertilizer at a rate of 337 kg/ha. A herbicide, chloramben (3-amino-2,5-dichlorobenzoic acid), was applied at time of planting at the rate of 3.37 kg/ha. All replications received two inches of supplemental water by sprinkler irrigation on July 2. Plants were individually harvested by handpicking during early October and the pods were placed in a forced air dryer at a temperature of 35°C until dry. The pods were hand threshed and the seed cleaned with a table model forced air seed cleaner.

Three Parent Diallel

Parents, F_1, and F_2 populations of the three parent diallel were grown in 1972. The parents were M101, M304, and M317. Seeds for planting F_1's came from crosses made in the greenhouse as previously described. The seed for growing the F_2 population was harvested from the F_1's grown in 1971. Subsequently, fifty seeds from each of the

five parents and the ten F_1 single crosses and two-hundred F_2 seeds bulked from each of the F_1's grown in 1971 were established under greenhouse conditions on June 10, 1972. Seeds were inoculated with 'EL' commercial culture inoculent before planting. Ten seedlings from each F_1 and parental accession and forty seedlings from each bulked F_2 accession were transplanted to the field in a randomized complete block design including five replications. A plot consisted of a single 4.5 m row with 45 cm spacing between plants. The spacing between rows was 90 cm. All replications received two inches of supplemental irrigation on July 10-11 and three inches on September 3-4. Fertilizer amendments were added to bring the plots up to soil test recommendation. A herbicide, chloramben (3-amino-2,5-dichlorobenzoic acid), was applied at the time of planting at a rate of 2.3 kg/ha. Plants were harvested separately by hand picking during mid-October. After harvesting, the pods were placed in a forced air dryer at a temperature of 35°C until dry. The pods were hand threshed and cleaned with a table model forced air seed cleaner.

Agronomic Characters Studied

All pre- and post-harvest observations were recorded on a per plant basis in both 1971 and 1972. The following characters were studied:

Yield. Yield observations consisted of the weight of threshed, cleaned seed from each plant and was expressed in grams.

Pod number per plant. The number of pods per plant was obtained by count of all mature pods produced on each plant.

Seed number per pod. Average seed number per pod was by count of seeds in ten randomly selected pods.

1000-seed weight. Seed weight was calculated by randomly selecting 100 seeds and multiplying the weight in grams by 10.

Days to first flower. Number of days from planting to the first flower.

Days to first ripe pod. Number of days from planting to first ripe pod.

Plant height. Height observations were taken by measuring the height of the main axis on each plant in centimeters.

Branch length. The first or lower lateral branch of individual plants was measured and recorded in centimeters.

Virus score. Visual estimation on the basis of 1 to 100 of the proportion of the plant showing virus symptoms as identified by leaf mosaic, leaf crinkling, plant stunting, and flower abortion. Identification of the specific virus (or viruses) present could not be made.

Mildew score. Visual rating for mildew on leaves at maturity based on a score of 1 (resistant) to 5 (susceptible).

Statistical Analysis of Data

Combining ability analyses for 1971 data were computed according to Griffing's (1956) Method 4, Model I, where only one set of F_1's is included. The 1972 data were treated by Griffing's Method 2, Model I, where the parents and one set of F_1's are included but not the reciprocal

F_1's. Inferences in these two methods are restricted to the varieties entering into the diallel cross since they are considered as a fixed set rather than a random sample from a population of genotypes. In the analysis of variance entries, years, replications, and genotypes were considered fixed. This analysis provided information on general and specific combining ability components of variance. Experimental error variances were used to test significance of mean squares associated with genotypes and genotypes x years.

Heritability values in the narrow sense were obtained by the regression of the F_1 means on their respective midparent means. Heritability estimates were obtained by utilizing the regression method as outlined by Falconer (1960). Simple correlation coefficients were calculated for each character measured. Broad sense heritability values were obtained by the following formula (Falconer, 1960):

$$\hat{\sigma}^2_{F_1} \equiv \hat{\sigma}^2_E$$

$$\hat{\sigma}^2_{F_2} \equiv \hat{\sigma}^2_G + \hat{\sigma}^2_E$$

$$h^2 \equiv \frac{\hat{\sigma}^2_{F_2} - \hat{\sigma}^2_{F_1}}{\sigma_{F_2}}$$

The estimated genetic advance for 5 percent, 10 percent, and 20 percent intensity was estimated by the following method discussed by Allard (1960):

$$G_s = (k) \left(\sqrt{\hat{\sigma}^2_{F_2}} \, (h^2) \right)$$

Heterosis was computed for each of the F_1 means for the 1971 experiment. Adjusted LSD values were used to test each hybrid midparent comparison as the hybrid means were based on one-half as many observations as the midparent values. Variance of a hybrid-midparent comparison may be defined as (3) (EMS) / (2) (N) (where EMS = experimental error mean square and N = the number of mean observations per entry across replications). LSD values were calculated by the formula, $LSD = t \sqrt{\frac{3 \text{ EMS}}{2N}}$. The LSD used to test the significance between the F_1's and their respective high parent is calculated by the formula, $LSD = t \sqrt{\frac{2 \text{ EMS}}{N}}$.

Data for all characters were analyzed on a plot mean basis. The data analyses reported in these experiments were made on an IBM 360-60 computer. Estimates of general and specific combining ability, narrow sense heritability, broad sense heritability, and correlation coefficients were obtained by using a Fortran program written by Dr. Ernest Hilderbrand, University of Missouri.

CHAPTER IV

EXPERIMENTAL RESULTS

In 1971, five parents and their ten possible F_1 crosses were grown. In 1972, three parents, their three possible F_1 crosses, and their respective three F_2 populations were grown. The results for 1971 were analyzed as a five parent diallel and will be given first. The results for 1972 and the combined 1971-72 results were analyzed separately as a three parent diallel.

Five Parent Diallel

The mean performance of the parents and F_1's for ten different characters are presented in Table 2. Mean squares from the randomized complete block analysis of variance conducted on parent and F_1 data for the ten different characters are presented in Table 3. Variance due to differences among genotypes was highly significant for each character except mildew score of parents and parents vs. F_1's. Variance due to replications was not significant except for mildew score. These differences were expected since the parent varieties were selected with a wide range in adaptive characteristics.

Table 2. Mean performance for ten characters involving five mungbean parents and the ten possible single crosses among them.

Parent or cross	Yield per plant g	Number pods per plant	Number seeds per pod	1000-seed weight g	Days to first flower	Days to first ripe pod	Plant height cm	Branch length cm	Virus score (1to100)	Mildew score (1to5)
					Parents					
M101	87.5	136.6	11.9	71.3	55.0	74.6	43.6	40.8	0.0	1.0
M304	30.7	66.2	10.8	57.2	52.6	74.3	38.2	28.1	21.0	1.0
M317	56.5	80.9	13.2	68.8	56.5	77.4	51.5	38.5	2.5	1.1
M299	14.5	55.1	7.7	37.1	49.3	70.1	27.5	17.6	6.9	1.1
M277	7.7	23.4	6.8	41.2	68.9	91.6	41.0	28.1	39.9	1.0
					F_1's					
M101xM304	86.7	143.3	13.1	61.8	55.0	74.5	41.1	37.3	0.7	1.0
M101xM317	88.0	138.3	11.9	62.7	58.2	77.9	55.6	45.4	1.0	1.0
M101xM299	65.4	150.4	10.7	49.5	45.5	66.9	41.0	35.5	1.4	1.1
M101xM277	79.0	131.0	12.1	60.1	59.6	78.7	55.0	42.4	1.3	1.0
M304xM317	60.1	110.8	11.9	53.5	54.5	74.7	46.7	33.6	9.7	1.2
M304xM299	24.1	73.9	9.6	46.0	47.7	68.2	32.7	25.8	7.5	1.1
M304xM277	27.9	71.0	12.6	47.5	61.8	82.4	53.3	39.4	19.0	1.0
M317xM299	33.4	95.2	10.3	42.0	43.0	65.0	35.5	27.8	0.9	1.3
M317xM277	41.6	89.0	10.8	55.6	66.2	85.0	65.5	49.1	2.5	1.1
M299xM277	27.3	104.8	8.7	39.6	53.1	73.3	43.1	34.1	22.8	1.1
LSD at .05 probability =	14.4	29.6	2.2	5.2	4.5	4.2	7.6	7.9	10.3	0.01

Table 3. Observed mean squares from randomized block analysis of variance for ten characters involving five mungbean parents and the ten possible single crosses in 1971.

Source of variation	df	Yield per plant	Number pods per plant	Number seeds per pod	1000-seed weight	Days to first flower	Days to first ripe pod	Plant height	Branch length	Virus score	Mildew score
Reps	4	148.8	970.9	4.0	8.2	4.5	6.6	17.3	45.4	40.5	34.8**
Entries	14	3872.9**	6914.1**	18.0**	576.6**	259.5**	246.6**	496.9**	364.0**	669.4**	24.8**
Parents	4	5378.1**	8697.7**	36.7**	1216.4**	277.8**	341.3**	381.0**	434.4**	1371.2**	10.5
F_1's	9	3272.7**	4157.8**	9.5**	336.5**	272.7**	216.2**	522.7**	304.4**	331.1**	32.4**
GCA	4	7049.5**	7917.4**	18.7**	704.4**	563.6**	450.6**	1067.6**	575.3**	478.4**	57.5**
SCA	5	251.4	1150.9	2.2	42.3*	40.0*	28.6*	86.8*	87.8	213.2**	12.4
Parents vs. F_1's	1	3251.5**	24585.4**	19.5**	177.7**	67.3*	141.3**	729.1**	618.1**	907.2**	15.6
Error	56	127.9	543.3	2.9	16.5	12.5	10.9	35.6	39.2	66.0	5.9

*Significant at the .05 level of probability.

**Significant at the .01 level of probability.

Combining Ability Analysis

Mean squares from the analyses of variance conducted on F_1 data for combining ability for yield per plant, pods per plant, seeds per pod, 1000-seed weight, days to first flower, days to first ripe pod, plant height, branch length, virus score, and mildew score are presented in Table 3. Variances due to differences among entries were highly significant for all characters. The genetic variability among F_1's for all characters was largely accounted for by highly significant general combining ability (gca) effects although significant specific combining ability (sca) effects were observed for five traits.

Estimates of gca effects associated with each of the parent varieties for the ten agronomic characters measured are presented in Table 4 along with the appropriate standard errors and LSD values. When yield per plant was considered, M101 had the only significant positive gca effect when compared with the other four lines. A similar observation was made for the number of pods per plant, with M101 again having a significant positive gca effect. Also, M101 had a significant positive gca effect for number of seeds per pod and 1,000-seed weight. A smaller positive, yet significant, gca effects for number of seeds per pod was observed with M317 and for 1,000-seed weight with M304. For days to flower and days to first ripe pod, significant negative (earliness)

Table 4. Estimates of general combining ability effects for ten characters involving five mungbean parents in 1971.

Character	Parents					Standard error		Least significant difference	
	M101	M304	M317	M299	M277	1[a]	2[b]	1[a]	2[b]
Yield	35.262*	-4.881	3.243	-21.104	-12.520	2.613	4.131	5.236	8.278
No. pods/plant	39.962*	-14.658	-3.261	-6.265	-15.777	5.384	8.512	10.789	17.058
No. seeds/pod	1.030*	0.830*	-0.080	-1.787	-0.153	0.225	0.619	0.451	1.241
1000-seed weight, g	8.918*	0.497	2.147*	-10.059	-1.503	0.938	1.483	1.880	2.973
Days to 1st flower	0.153	0.400	1.333	-9.503*	7.617	0.816	1.290	1.634	2.584
Days to 1st ripe pod	-0.154	0.418	1.262	-8.418*	6.892	0.761	1.203	1.525	2.411
Plant height, cm	1.643	-4.643	5.140*	-11.834	9.694*	1.378	2.179	2.761	4.366
Branch length, cm	4.529	-3.629*	1.979	-8.911*	6.032	1.446	2.287	2.899	4.583
Virus score, (0-100)	-7.433*	3.360	-4.185*	1.959	6.299	1.876	2.966	3.760	5.945
Mildew score, (1-5)	-0.062*	-0.019	0.067	0.064	-0.051*	0.018	0.028	0.036	0.056

[a]SE 1 and LSD 1 = Standard error and least significant difference between effect and zero.

[b]SE 2 and LSD 2 = Standard error and least significant difference between two effects.

*Significant at the .05 level of probability.

gca effects were noted for M299. When plant height was considered, both M277 and M317 had significant positive gca effects. For branch length M299 and M304 had significant negative (shortness) gca effects. Both M101 and M317 had significant negative (resistance) gca effects for virus expression, while M101 and M277 had significant negative (resistance) gca effects for mildew score. In addition, either negative or positive values, depending on the character under consideration, were observed among all of the crosses involving all ten characters.

Estimates of sca effects associated with individual crosses for each of the above characters are presented in Tables 6 to 15 along with standard errors for comparison of effects of crosses having only one parent or no parents in common. The crosses M304 x M317 and M299 x M277 exhibited the highest positive effects for yield per plant. M299 and M277 as parents were the lowest yielding. The crosses M304 x M317, M299 x M277, and M101 x M304 had the highest sca effects for number of pods per plant. The crosses M317 x M299 and M304 x M277 had the highest sca effects for number of seeds per pod. The M304 x M299 and M317 x M277 crosses had the largest sca effects for 1,000-seed weight. For days to first flower and days to first ripe pod, M101 x M299 exhibited the largest negative (earliness) sca effect. For plant height, M101 x M299 had the larger sca effect. Both M317 x M299 and M101 x M277 exhibited large negative (shortness) effects for

Table 5. Estimates of specific combining ability effects for yield per plant (1971).

Parents	M304	M317	M299	M277
M101	3.022	-3.886	-2.079	2.943
M304		8.407	-3.367	-8.062
M317			-2.097	-2.424
M299				7.543

SE and LSD for effects with no parents in common = 4.131 and 8.278, respectively.

SE and LSD for effects with one parent in common = 5.842 and 11.707, respectively.

Table 6. Estimates of specific combining ability effects for number of pods per plant (1971).

Parents	M304	M317	M299	M277
M101	7.278	-9.204	5.892	-3.967
M304		17.963	-15.923	-9.319
M317			-6.008	-2.752
M299				16.038

SD and LSD for effects with no parents in common = 8.512 and 17.058, respectively.

SE and LSD for effects with one parent in common = 12.038 and 24.124, respectively.

Table 7. Estimates of specific combining ability effects for number of seeds per pod (1971).

Parents	M304	M317	M299	M277
M101	0.056	-0.422	0.310	-0.056
M304		-0.132	-0.638	0.714
M317			0.826	-0.272
M299				-0.497

SE and LSD for effects with no parents in common = 0.619 and 1.241, respecitvely.

SE and LSD for effects with one parent in common = 0.876 and 1.755, respectively.

Table 8. Estimates of specific combining ability effects for 1000-seed weight (1971).

Parents	M304	M317	M299	M277
M101	0.536	-0.234	-1.168	0.866
M304		-0.963	3.747	-3.320
M317			-1.918	3.115
M299				-0.661

SE and LSD for effects with no parents in common = 1.483 and 2.973, respectively.

SE and LSD for effects with one parent in common = 2.098 and 4.204, respectively.

Table 9. Estimates of specific combining ability effects for days to first flower (1971).

Parents	M304	M317	M299	M277
M101	-0.574	2.252	0.427	-1.262
M304		-1.665	2.381	-0.659
M317			-3.337	2.751
M299				0.529

SE and LSD for effects with no parents in common = 1.290 and 2.584, respectively.

SE and LSD for effects with one parent in common = 1.824 and 3.655, respectively.

Table 10. Estimates of specific combining ability effects for days to first ripe pod (1971).

Parents	M304	M317	M299	M277
M101	-0.237	2.101	0.805	-2.699
M304		-1.698	1.559	0.377
M317			-2.529	2.127
M299				0.165

SE and LSD for effects with no parents in common = 1.203 and 2.411, respectively.

SE and LSD for effects with one parent in common = 1.702 and 3.410, respectively.

Table 11. Estimates of specific combining ability effects for plant height (1971).

Parents	M304	M317	M299	M277
M101	-2.834	1.817	4.273	-3.256
M304		-0.775	2.241	1.338
M317			-4.752	3.680
M299				-0.176

SE and LSD for effects with no parents in common = 2.179 and 4.366, respectively.

SE and LSD for effects with one parent in common = 3.081 and 6.174, respectively.

Table 12. Estimates of specific combining ability effects for branch length (1971).

Parents	M304	M317	M299	M277
M101	-0.364	2.146	3.110	-4.893
M304		-1.502	1.632	0.233
M317			-5.024	4.379
M299				0.281

SE and LSD for effects with no parents in common = 2.287 and 4.583, respectively.

SE and LSD for effects with one parent in common = 3.234 and 6.482, respectively.

Table 13. Estimates of specific combining ability effects for virus score (1971).

Parents	M304	M317	M299	M277
M101	-1.960	5.970	0.206	-4.216
M304		3.834	-4.543	2.670
M317			-3.506	-6.298
M299				7.844

SE and LSD for effects with no parents in common = 2.966 and 5.945, respectively.

SE and LSD for effects with one parent in common = 4.195 and 8.407, respectively.

Table 14. Estimates of specific combining ability effects for mildew score (1971).

Parents	M304	M317	M299	M277
M101	0.013	-0.054	0.006	0.035
M304		0.034	-0.053	0.006
M317			0.054	-0.034
M299				-0.007

SE and LSD for effects with no parents in common = 0.028 and 0.056, respectively.

SE and LSD for effects with one parent in common = 0.040 and 0.080, respectively.

branch length. The crosses M101 x M277, M304 x M299, and M317 x M277 had the higher negative (resistance) effects for virus score. For mildew resistance M101 x M317 and M304 x M299 had the larger negative (resistance) sca effects.

Heritability and Correlation Coefficients

Narrow sense heritability estimates were obtained from midparent-progeny regressions. These values along with the respective standard error of the mean for the ten characters studied are presented in Table 15. Most of the regression coefficients obtained are relatively high, although they ranged from 0.219 for seeds per pod to 1.317 for plant height. A regression coefficient (up to b = 1.0) is an indication of additive gene action. Values where b $>$ 1.0 indicate both additive and non-additive gene action.

Simple phenotypic correlation coefficients were calculated and are presented in Table 16. Yield was significantly correlated with characters associated with plant size (plant height and branch length). Plant size is important because it provides capacity to set and hold a large number of pods. Maximum plant size would be favored in this experiment since plants were space planted thus reducing competition between plants. Yield was also significantly correlated with each of the components of yield, pods per plant, seeds per pod, and 1000-seed weight.

Table 15. Regression coefficients of midparent with F_1 mean for ten characters analyzed.

Character	Midparent-progeny regression (b)
Yield	1.166 ± 0.117*
Pods/plant	0.776 ± 0.166*
Seeds/pod	0.220 ± 0.173
1000-seed weight	0.709 ± 0.096*
Days to 1st flower	1.085 ± 0.183*
Days to 1st ripe pod	0.923 ± 0.151*
Plant height	1.317 ± 0.234*
Branch length	0.911 ± 0.216*
Virus score (0 to 100)	0.484 ± 0.129*
Mildew score (1 to 5)	0.994 ± 0.252*

*Significant at the .05 level of probability when n = 50.

Table 16. Correlation coefficients among the mungbean characters studied (1971).

Character	Yield	Pods per plant	Seeds per pod	1000-seed weight	Days to 1st flower	Days to 1st ripe pod	Plant height	Branch length	Virus score	Mildew score
Yield	1.000									
Pods per plant	0.878*	1.000								
Seeds per pod	0.601*	0.474*	1.000							
1000-seed weight	0.764*	0.473*	0.574*	1.000						
Days to 1st flower	-0.051	-0.304*	0.025	0.201	1.000					
Days to 1st ripe pod	-0.137	-0.383*	-0.028	0.141	0.983*	1.000				
Plant height	0.432*	0.367*	0.349*	0.443*	0.525*	0.467*	1.000			
Branch length	0.607*	0.554*	0.382*	0.543*	0.371*	0.300*	0.900*	1.000		
Virus score	-0.630*	-0.633*	-0.497*	-0.406*	0.409*	0.496*	-0.165	-0.261*	1.000	
Mildew score	-0.117	0.027	-0.073	-0.261*	-0.410*	-0.380*	-0.130	-0.190	-0.106	1.000

*Significant at the .05 level of probability.

A significant and negative correlation was obtained between yield and virus score. The correlation of yield with mildew score was also negative but not significant.

Pods per plant were significantly correlated with the characters associated with plant size and negatively correlated with early maturity and virus disease damage. Number of seeds per pod was significantly correlated with the characters associated with plant size while exhibiting a significant negative correlation to virus expression. There was a significant correlation between 1000-seed weight and the plant size characters. Seed weight exhibited a significant negative correlation with both virus and mildew scores.

The plant maturity characters, number of days to first flower and number of days to first ripe pod were highly correlated. Both of these characters were positively correlated with plant size and virus score and were negatively correlated with mildew score.

Plant height and branch length exhibited a high significant positive association. Branch length also had a significant negative correlation with the virus score.

Heterosis

Heterosis, expressed as a percentage of the midparent (MP) and of the high parent (HP) for the ten F_1 populations involving ten characters are given in Table 17. The mean heterosis for yield as a percentage of their respective midparents of the ten F_1's averaged 142.2

Table 17. F_1 expressed as a percent of midparent (MP) and high parent (HP) (or lowparent (LP)) for ten characters in ten mungbean crosses (1971).

Character		M101 x M304	M101 x M317	M101 x M299	M101 x M277	M304 x M317	M304 x M299	M304 x M277	M317 x M299	M317 x M277	M299 x M277	Mean
Yield per plant	MP	146.7**	122.1*	128.2*	166.0**	137.8**	106.2	145.3	94.1	129.6	246.0*	142.2
	HP	99.1	100.5	74.7	90.3	106.4	78.2	90.9	59.1	73.6	188.3*	96.1
Number pods per plant	MP	141.4**	127.1*	156.8**	164.0**	150.5**	121.8	158.8*	140.0*	171.2**	268.0**	160.0
	HP	105.0	101.2	110.1	95.9	137.0*	111.6	107.3	117.7	110.0	190.2**	118.6
Seeds per pod	MP	114.9	94.4	109.2	128.7**	99.2	103.2	143.2**	98.1	108.0	119.2	111.8
	HP	110.1	100.0	89.9	101.7	90.2	88.9	116.7	78.0	81.8	113.0	97.0
1000 seed weight	MP	96.1	89.4	91.3	106.9	84.9	97.5	96.5	79.3	101.1	101.0	94.4
	HP	86.7	87.9	69.4	84.3	77.8	80.4	83.0	69.9	80.8	96.1	81.6
Days to first flower	MP	102.2	104.3	87.2**	96.1	99.8	93.7	101.6	81.1**	105.6	89.9**	96.2
	LP	104.6	105.8	92.3	108.4	103.6	97.0	117.5	87.0**	117.2	107.7	104.1
Days to first ripe pod	MP	100.3	102.5	92.4**	94.7*	98.3	94.5*	99.2	88.1**	100.6	90.6**	96.1
	LP	100.5	104.4	95.4	105.5	100.4	97.3	110.8	92.7	109.8	104.8	102.2
Plant height	MP	100.5	117.0*	115.2	130.0**	104.0	114.6	134.6**	89.9	141.5**	125.7**	117.3
	HP	94.3	108.0	94.3	126.2*	90.7	98.7	130.0**	68.9	127.2**	105.1	104.3
Branch length	MP	108.1	114.4	121.2	122.9*	100.9	112.7	140.2**	88.3	147.5**	148.9**	120.5
	HP	91.4	111.3	86.8	103.9	87.3	91.8	140.2**	64.4	127.5**	121.4	102.6
Virus score	MP	6.2*	83.2	41.2	0.7**	82.5	53.5	62.4*	20.2	11.8**	97.4	45.9
	LP					387.6	108.1	90.5	38.0	100.0	330.3	105.8
Mildew score	MP	100.0	97.2	104.8	98.0	105.3	102.9	98.1	115.6	98.2	101.9	102.2
	LP	101.0	103.0	109.0	100.0	114.9	105.9	100.0	117.8	101.9	103.8	105.7

*Significantly different from the mid- or high parent at the .05 level of probability.

**Significantly different from the mid- or high parent at the .01 level of probability.

percent. Heterosis for yield was significant in 6 of 10 crosses. Only one F_1 significantly exceeded the high parent in yield. Among the components of yield, the number of pods per plant showed the greatest expression of midparent heterosis with an average of 160.0 percent over all F_1's. Heterosis was significant in 9 of the 10 crosses. Heterosis for number of pods per plant based on the high parent was significant for only two of the F_1's. For seeds per pod, overall, the F_1's averaged 111.8 percent of the respective midparents, but the increase was significant in only 2 crosses and none of the F_1's significantly exceeded the high parent. For 1,000-seed weight, overall, the F_1's averaged 94.4 percent of the respective midparents. None were significantly greater than the midparent or high parent. These results indicated that the increase in yield of the F_1 over the midparent was a result of a large increase in number of pods and a small increase in the number of seeds per pod which was partly offset by a small loss in 1000-seed weight.

The number of days to first flower and days to first ripe pod indicated the F_1's were always earlier than the midparent. Over all crosses, the F_1's averaged 96.2 percent of their respective midparents for days to first flower and 96.1 percent for days to first ripe pod. In one cross the number of days to first flower was significantly less (earlier) than the low parent (early parent). One parent in this cross, M299, was the earliest in flowering

among the five parents.

Plant size is determined by height and branch length, and a heterotic effect was indicated for both of these characters. For plant height, overall, the F_1's averaged 117.3 percent of their respective midparents with significant increases over the midparent in five crosses and a significant increase over the high parent in three crosses. Each of these three crosses had M277 as one of the parents. For branch length, overall, the F_1's averaged 120.5 percent of their respective midparents with the increases significant over the midparent in four crosses and over the high parent in two crosses. All of the crosses with significant midparent heterosis for branch length had M277 as a parent.

The diseases observed were virus and mildew. A low score for these diseases denotes resistance. For virus, overall, the F_1's averaged 45.9 percent of their respective midparents indicating they were more resistant than the average of their parents. In four crosses the F_1's were significantly less than the average of the parents. None of the F_1's was significantly better than the low or resistant parent. Comparisons could not be made with the M101 parent since its virus score was zero. With respect to mildew the F_1's averaged 102.2 percent of the respective midparents and none of the F_1's was significantly different from the midparent or the low parents.

Three Parent Diallel

The three parent diallel experiment involving the mungbean parental varieties, M101, M304, and M317, and the three possible F_1 crosses among them and their F_2 populations of crosses was grown in 1972. The data recorded in Table 18. Mean squares from the randomized complete block analysis of variance are presented in Table 19. Variance due to differences among entries was significant for all characters except mildew score. Parent varieties differed significantly for all characters except days to first flower, days to first ripe pod, and mildew score. The F_1's differed significantly for all characters except yield, seeds per pod, virus score and mildew score. The F_2 populations differed significantly only for 1000-seed weight.

Since the three varieties grown in 1972 had been grown in 1971 also, data for the two years have been combined and analyzed. The mean squares of the pooled data for the ten characters are presented in Table 20. From the pooled data, variance due to differences between years was significant for yield, pods per plant, days to first flower, days to first ripe pod, branch length, and mildew score, but replications within years was not significant for any character. Variances due to entries was again significant for all characters except mildew score. That genotypes accounted for the major portion of the variation when analyzed over years could have been expected because the parent varieties were selected to represent a wide

Table 18. Mean performance for ten characters involving three mungbean parents and the three possible F_1 and F_2 populations of crosses among them (grown in 1972).

Parent or cross	Yield per plant g	No. pods per plant	No. seed per pod	1000-seed weight g	Days to first flower	Days to first ripe pod	Plant height cm	Branch length cm	Virus score (0to100)	Mildew score (1to5)
						Parents				
M101	60.4	83.6	11.9	74.6	61.4	81.1	40.1	46.2	0.5	1.8
M304	21.1	52.4	11.2	54.8	64.1	85.9	40.8	34.6	36.3	2.7
M317	37.7	59.3	12.6	63.1	63.4	85.7	49.2	44.4	7.3	2.7
						F_1's				
101 x 304	69.7	154.9	12.4	59.4	57.6	76.8	44.0	38.1	4.0	2.0
101 x 317	71.0	103.3	12.9	66.2	62.8	83.1	45.8	46.4	1.0	2.4
304 x 317	75.3	128.3	12.8	58.9	59.2	78.6	52.3	40.9	3.0	1.6
						F_2's				
101 x 304	58.1	93.2	12.8	63.8	61.3	81.2	44.9	41.2	2.0	2.4
101 x 317	51.9	76.8	12.0	64.3	64.2	84.6	48.3	42.0	5.3	2.6
304 x 317	46.6	90.9	11.9	55.7	61.5	82.0	49.0	41.7	6.6	2.7

Table 19. Mean squares for ten characters involving three mungbean parents and the three possible F_1 and F_2 populations of crosses among them (grown in 1972).

Source of variation	df	Yield per plant	No. pods per plant	No. seeds per pod	1000-seed weight	Days to first flower	Days to first ripe pod	Plant height	Length first branch	Virus score	Mildew score
Reps	4	593.8*	1236.0**	0.56	32.9*	22.5*	33.2*	45.0*	88.5**	29.5	0.5
Entries	8	1530.5**	5200.5**	1.62*	184.0**	24.6*	48.1**	82.2**	70.9**	619.4**	0.0
Parents	2	1942.9**	1340.5**	2.31*	497.1**	9.9	36.3	127.8**	194.4**	1811.6**	1.5
F_1's	2	43.9	3325.9**	0.35	83.3**	34.8*	52.3*	95.3**	88.1**	11.7	0.8
F_2's	2	165.4	395.9	1.23	116.2**	12.8	16.0	24.1	0.8	28.3	0.12
Generations	2	3970.0**	15739.7**	2.57*	39.5*	9.8	87.7**	81.7**	0.1	626.2**	1.2
Error	32	158.6	203.3	0.54	10.53	8.1	11.7	14.3	16.1	49.5	0.3

*Significant at .05 level of probability.

**Significant at .01 level of probability.

Table 20. Mean squares over years (1971 and 1972) for ten characters involving three mungbean parents and the three possible F_1 populations of crosses among them.

Source of Variation	df	Yield per plant	Pods per plant	Seeds per pod	1000-seed weight	Days to first flower	Days to first ripe pod	Height	Branch length	Virus score	Mildew score
Years	1	2295.1**	3704.6**	0.43	0.98	557.6**	594.8**	8.3	304.6**	123.6	19.2**
Replications within years	8	296.2	397.7	0.96	22.5	8.9	12.3	15.7	31.7	69.3	0.2
Entries	5	4539.6**	11,480.8**	4.70**	421.7**	27.5*	53.6**	248.5**	270.8**	1155.1**	0.5
Parents	2	5800.1**	7152.1**	8.73**	728.3**	9.8	34.1	325.6**	424.3**	2325.3**	0.8*
F_1's	2	415.8	2796.8**	0.45	169.7**	51.9*	63.4**	192.4**	235.8**	77.1	0.3
Parents vs F_1's	1	10,266.0**	37,505.6**	5.12*	312.5**	13.9	73.2**	206.4**	35.8	970.5**	0.4
GCA	2	5886.3**	7540.1**	5.71**	895.7**	28.0*	43.8*	498.7**	637.9**	2143.9**	0.4
SCA	3	3641.8**	14,109.6**	4.04*	106.2**	27.1*	61.1**	81.7*	26.1	495.8**	0.6
Entires x years	5	535.4*	1821.3**	1.13	47.9*	22.9	28.5	78.0**	20.4	132.1	0.6
Parents x years	2	193.1	1075.6	0.66	52.6*	19.6	16.6	26.6	0.8	145.3	0.6
F_1's x years	2	866.8*	2061.0**	2.24	40.9	3.1	6.0	167.8**	34.7	65.3	0.6
Parents vs F_1's x years	1	557.1	2833.6**	0.87	52.5*	68.9*	97.4**	1.5	31.0	239.6	0.6
Error	40	186.9	352.9	1.02	16.1	10.3	10.8	20.2	20.6	65.7	0.2

*Significant at .05 level of probability.
**Significant at .01 level of probability.

range in adaptive characters.

Combining Ability Analysis

The combining ability of the three parent lines was analyzed from the pooled 1971 and 1972 data. Significant variances for all characters, except mildew score, due to differences among genotypes were accounted for by gca and sca. Estimates of gca effects associated with each of the parent varieties for the ten agronomic characters studied are presented in Table 21 along with the appropriate standard errors and LSD values. When yield per plant was considered, M101 had the only significant positive gca effect as compared with the other two lines. A similar observation can be made for the number of pods per plant with M101 again having a significant positive gca effect. Positive but nonsignificant effects were observed for number of seeds per pod for M101 and M317. M101 also had a positive significant gca effect for 1000-seed weight, M317 showed a positive but nonsignificant effect, and M304 a significant negative gca effect. Both M101 and M304 exhibited nonsignificant negative (earliness) gca effects for number of days to first flower and number of days to first ripe pod. Variety M317 exhibited significant positive gca effects for plant height while M304 exhibited significant negative (shortness) gca effects for branch length. Both M101 and M317 had negative (resistance) gca effects for virus score with the gca effect for M101 being significant. M101 also exhibited a nonsignificant negative

Table 21. Estimates of general combining ability effects for ten characters involving three parents and the three possible F_1 populations from crosses among them (grown in 1971 and 1972).

Character	Parents			Standard error		Least significant difference	
	M101	M304	M317	1[a]	2[b]	1[a]	2[b]
Yield	11.471*	-10.099*	-1.371	2.233	3.867	4.512	7.815
No. pods per plant	14.155*	-6.389	-7.765	3.068	5.314	6.200	10.739
No. seeds per pod	0.0148	-0.345	0.330	0.165	0.286	0.334	0.579
1000-seed weight	4.040*	-4.399*	0.359	0.656	1.136	1.325	2.295
Days to first flower	-0.051	-0.721	0.772	0.524	0.908	1.059	1.835
Days to first ripe pod	-0.582	-0.470	1.052	0.536	0.929	1.084	2.513
Plant height	-1.207	-2.377*	3.583*	0.735	1.272	1.485	2.572
Branch length	2.508	-4.089*	1.582	0.741	1.283	1.497	2.593
Virus score	-5.033*	7.403*	-2.371	1.324	2.293	2.676	4.635
Mildew score	-0.100	0.014	0.086	0.806	0.194	0.163	0.524

[a]SE1 and LSD1 standard error and least significant difference between effect and 0.

[b]SE2 and LSD2 standard error and least significant difference between two effects.

*Significant at .05 level of probability.

(resistance) gca effect for the mildew score. In addition, negative or positive estimates, depending on the character under consideration, were observed for all of the crosses involving all ten characters measured.

Estimates of sca effects associated with individual crosses for each of the above characters are presented in Tables 22 to 33. Standard errors and LSD's for comparison of parental effects among crosses with one parent in common, and those crosses with no parents in common. The crosses M101 x M304 and M304 x M317 exhibited the highest positive sca effects for yield per plant, number of pods per plant, and number of seeds per pod. There were no crosses with positive sca effects for 1000-seed weight. Two crosses, M101 x M304 and M304 x M317, exhibited negative (earlier) sca effects for number of days to first flower and first ripe pods. All crosses, M101 x M304, M101 x M317, and M304 x M317 exhibited positive sca effects for plant height. Only M101 x M304 showed negative (shortness) sca effects for branch length. Both M101 x M304 and M304 x M317 exhibited negative (resistance) sca effects for virus and mildew expression.

Heritability and Estimated Genetic Advance

Broad sense heritability estimates were calculated for the ten characters from the 1972 data. These estimates are presented in Table 32 for the individual crosses and for the pooled data over all crosses. Except for number of pods per plant, which had a heritability estimate of

Table 22. Estimates of specific combining ability effects for yield (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	-11.050	14.793	7.308
M304		-15.966	17.140
M317			-12.22

SE and LSD for parental effects = 3.867 and 7.815, respectively.

SE and LSD for effects with no parents in common = 6.698 and 13.536, respectively.

SE and LSD for effects with one parent in common = 7.734 and 15,630, respectively.

Table 23. Estimates of specific combining ability effects for number of pods per plant (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	-23.058	36.534	9.582
M304		-32.712	28.890
M317			

SE and LSD for parental effects = 5.314 and 10.739, respectively.

SE and LSD for effects with no parents in common = 9.204 and 18.601, respectively.

SE and LSD for effects with one parent in common = 10.628 and 21.478, respectively.

Table 24. Estimates of specific combining ability effects for number of seed per pod (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	-0.349	0.868	-0.169
M304		-0.523	0.178
M317			-0.445

SE and LSD for parental effects = 0.286 and 0.579, respectively.

SE and LSD for effects with no parents in common = 0.496 and 1.002, respectively.

SE and LSD for effects with one parent in common = 0.573 and 1.157, respectively.

Table 25. Estimates of specific combining ability effects for 1000-seed weight (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	2.197	-1.736	-2.658
M304		2.094	-2.452
M317			2.555

SE and LSD for parental effects = 1.136 and 2.295, respectively.

SE and LSD for effects with no parents in common = 1.967 and 3.976, respectively.

SE and LSD for effects with one parent in common = 2.272 and 4.591, respectively.

Table 26. Estimates of specific combining ability effects for number of days to first flower (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	-0.061	-1.288	1.410
M304		1.426	-1.563
M317			0.077

SE and LSD for parental effects = 0.908 and 1.835, respectively.

SE and LSD for effects with no parents in common = 1.573 and 3.179, respectively.

SE and LSD for effects with one parent in common = 1.816 and 3.670, respectively.

Table 27. Estimates of specific combining ability effects for number of days to first ripe pod (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	0.308	-1.908	1.291
M304		2.302	-2.697
M317			0.703

SE and LSD for parental effects = 0.929 and 1.878, respectively.

SE and LSD for effects with no parents in common = 1.610 and 3.254, respectively.

SE and LSD for effects with one parent in common = 1.859 and 3.756, respectively.

Table 28. Estimates of specific combining ability effects for plant height (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	-1.496	0.418	2.574
M304		-1.495	2.571
M317			-2.573

SE and LSD for parental effects - 1.272 and 2.572, respectively.

SE and LSD for effects with no parents in common = 2.204 and 4.454, respectively.

SE and LSD for effects with one parent in common = 2.545 and 5.143, respectively.

Table 29. Estimates of specific combi
for branch length (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	-1.003	-0.257	2.262
M304		0.006	0.245
M317			-1.254

SE and LSD for parental effects = 1.283 and 2.593, respectively.

SE and LSD for effects with no parents in common = 2.222 and 4.491, respectively.

SE and LSD for effects with one parent in common = 2.566 and 5.186, respectively.

Table 30. Estimates of specific combining ability effects for virus score (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	3.064	-7.297	1.170
M304		6.618	-5.938
M317			2.384

SE and LSD for parental effects = 2.293 and 4.635, respectively.

SE and LSD for effects with no parents in common = 3.972 and 8.027, respectively.

SE and LSD for effects with one parent in common = 4.5867 and 7.270, respectively.

Table 31. Estimates of specific combining ability effects for mildew score (pooled data 1971 and 1972).

Parents	M101	M304	M317
M101	-0.045	-0.022	0.111
M304		0.184	-0.347
M317			0.118

SE and LSD for parental effects = 0.194 and 0.392, respectively.

SE and LSD for effects with no parents in common = 0.241 and 0.488, respectively.

SE and LSD for effects with one parent in common = 0.278 and 0.563, respectively.

Table 32. Broad sense heritability estimates for ten characters involving three mungbean parents and the three possible F_1 and F_2 populations of crosses, grown in 1972.

Cross	Yield per plant %	No. pods per plant %	No. seeds per pod %	1,000-seed weight %	Days to first flower %	Days to first ripe pod %	Plant height %	Branch length %	Virus score %	Mildew score %
M101 x M304	46.0	0	31.2	30.2	77.8	90.9	62.8	0	100.0	83.5
M101 x M317	54.6	50.1	92.0	92.8	77.3	87.3	87.3	81.1	100.0	95.6
M304 x M317	19.1	0	24.7	-33.4	79.2	94.4	52.1	43.4	82.8	82.8
Over all crosses	44.8	0	57.9	71.0	78.1	89.5	75.1	42.0	95.1	89.7

zero in two crosses, heritability estimates over all crosses were high for all characters. Previous observations of the parental lines in these crosses indicated that the characters 1000-seed weight, days to first flower and first ripe pod, height, and disease ratings were relatively stable characteristics and do not vary greatly from season to season indicating a low environmental effect. By contrast, number of pods per plant varied greatly from season to season and from plant to plant within the same season.

Estimated genetic advance for a selection intensity of 5 percent, 10 percent, and 20 percent was calculated from the 1972 F_2 population and using the pooled heritability estimates for the characters yield per plant, number of seeds per pod, 1000-seed weight, days to first flower, plant height, and branch length. These data are presented in Table 33 and indicate that each character could be improved by selection within the population studied. These results might be expected since the estimates of heritability were high. No genetic advance was calculated for numbers of pods per plant since heritability for this character was zero in two crosses. Since virus and mildew scores were visual observations rather than discrete measurements the genetic advance was not computed.

Table 33. Estimated genetic advance for six characters involving three mungbean crosses, with selection intensities of 5%, 10%, and 20%.

	Yield per plant g			Number seeds per pod			1000-seed weight g		
	5%	10%	20%	5%	10%	20%	5%	10%	20%
Mean of F_2		(52.2)			(12.2)			(61.2)	
Estimated genetic advance	26.1	22.3	17.8	3.0	2.6	2.1	23.4	20.0	15.9
Expected mean of F_3 progenies	78.3	74.5	70.0	15.2	14.8	14.3	84.6	81.2	77.1
	Days to 1st flower			Plant height cm			Branch length cm		
Mean of F_2		(62.4)			(47.4)			(41.6)	
Estimated genetic advance	12.5	10.9	8.7	18.0	15.4	12.3	7.8	6.7	5.3
Expected mean of F_3 progenies	49.9	51.5	53.7	65.4	62.8	59.7	33.8	34.9	36.3

CHAPTER V

DISCUSSION

The total observed variation for all characters within a plant population is the result of: (1) the genetic composition, (2) environment, and (3) the genetic-environmental interaction. Of this variation, the genetic composition is of particular interest to the plant breeder, since it constitutes the basis for which progress can be made in a breeding program. Considering the genetic source of variation, a particular plant character can be described as either qualitatively or quantitatively inherited. Qualitative inheritance usually involves a small number of genes, and the character exhibits discontinuous variation in segregating populations. Quantitatively inherited characters show continuous variation in segregating populations as they are controlled by a large number of genes which have similar, small and cumulative effects. This latter type of inheritance can be partitioned into component parts which include: (1) that due to additive effect of genes, (2) a dominance component arising from interactions of alleles, and (3) an epistatic part associated with interaction of nonalleles which do not behave in an additive manner. Quantitatively inherited characters are particularly susceptible to environmental

influences.

Even though the genetic composition provides the basis for plant improvement, the breeder of self pollinating crops, such as mungbeans, can utilize only a segment of the total genetic variability present. This variability includes the additive portion and those epistatic effects which behave in an additive manner, since only this type of gene action can be retained by subsequent inbreeding. It is, therefore, important for the breeder of self pollinated crops to obtain not only estimates of the total amount of observed variation that is due to the genetic composition, but also to determine the predominate type of gene action which is contributing to a particular character. Such information would be particularly beneficial if it could be obtained and identified for individual crosses in the early generations, preferably the F_1 generation, thereby helping the plant breeder in choosing the best parental source for line development. These problems are particularly difficult for a breeder working with a quantitatively inherited character such as yield that is affected by a large number of genes.

As indicated by the analysis of variance for this study, the genetic variation for each character was largely accounted for by the variance due to general combining ability. According to Sprague and Tatum (1942), general combining ability provides a measure of additive gene action. On the basis of this assumption, the present

results are therefore in agreement with those of Dhaliwal and Singh (1970) and Singh and Jain (1971) who also found that most of the total genetic variability for a number of characters studied in Phaseolus mungo L. and Phaseolus aureus Roxb. crosses was due to additive effects of genes. The occurrence of significant specific combining ability variation for five of the ten characters measured in the five parent diallel and for nine characters in the three parent diallel studies suggests that the genetic variation present for these traits was due in part to nonadditive effects.

On the basis of estimates of the general combining ability effects for yield and the components of yield, the best parent among the present set was M101. The crosses between M101 and the other four parents would consequently be expected to provide the best source materials for the selection of segregates superior to the best parent in yielding ability. Direct selection for yield in segregating generations of crosses involving this parent would presumably result in yield improvement. Improvement in yielding capacity through selection based on yield components may be feasible if selection for high expression in one component does not result in a significant reduction in the expression of another. Thus, selection for increased number of seeds per pod or 1000-seed weight within populations arising from the crosses M101 x M304 and M101 x M317, respectively, might be expected to result in improved yield since M101 and M304 exhibited the highest

general combining ability effects for number of seeds per pod while M101 and M317 exhibited the highest general combining ability effects for 1000-seed weight.

Since variety M299 was the only parent having negative (earliness) general combining ability effects for early flowering and early pod maturity, the crosses involving this parent should provide a relatively broad range of segregates from which types with earlier flowering and pod maturity could be selected.

The highest yielding mungbean parental variety in this study had a prostrate habit of growth which when mature becomes a bushy, tangled mass. This growth habit creates a tight leaf canopy which could hinder air exchange and prevent full utilization of sunlight. For maximizing yield the breeder is concerned about developing an erect plant type with branches being distributed on the plant in such a manner that there appears to be an open canopy of small leaves which in a three dimensional view would appear to be uniformly distributed. Thus it would appear that plant height and branch length are two important factors to consider in growth habit. The desirable plant type for the mungbean would probably be an erect, christmas tree shaped plant with the petioles being positioned in an erect manner and the petiolules at a somewhat horizontal plane at the bottom of the plant and progressing to a more vertical plane as the plant develops vegetatively (Figure 1). This habit of growth emphasizes plant height and

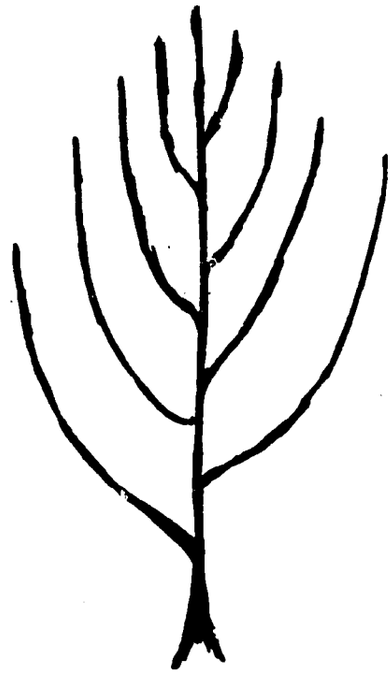

Figure 1. Conceptual drawing of an ideal mungbean plant type.

branch length. M277 has the highest general combining ability for plant height. Both M299 and M304 have negative general combining effects for branch length indicating that their progenies should have shorter branches. The crosses, M277 x M299 and M277 x M304 should provide a broad range of segregates from which erect types with shorter branches could be selected. This hypothesis is illustrated by Figures 2 to 6 which illustrates the lack of erectness in the progeny of the M101 x M277 cross as compared with the M277 x M304 cross. In this study, the more desirable genotype was obtained from the M277 x M304 cross as would be predicted from the combining ability studies.

As indicated earlier, when each character was considered individually, the general combining ability analysis indicated that a large part of the total genetic variance was due to additive gene action. This was in agreement with the heritability values obtained from parent-progeny regression for each character in 1971 as the heritability value for each character was high, indicating large additive effects existing in this population for each character.

Yield is generally considered to be complex in its inheritance and low in heritability. The primary components of yield may be less complex in inheritance and the heritability of the components would generally appear to be greater than yield <u>per se</u>. The correlations between

Figure 2. Parent M101, prostrate type.

Figure 3. Parent M277, erect growth type.

Figure 4. F_1, M101 x M277, prostrate x erect growth habit.

Figure 5. Parent M304, bushy erect growth habit.

Figure 6. F_3 selection from M304 x M277 cross, erect growth habit.

number of pods per plant and yield, number of seed per pod and yield, and 1000-seed weight and yield were high. The high correlation values indicated that these two characters were highly heritable. In addition, high correlation values indicated that a major portion of the genotypic variance was of the additive type. Since the number of pods was greatly influenced by the environment, this component seems to be questionable in its value for predicting yield.

Disease, particularly diseases caused by viruses, can cause extreme damage and loss of productivity in the mungbean plant. Very little attention has been given to breeding for disease resistance in mungbeans as compared to such objectives as higher yield and the components of yield. Disease losses are important in the mungbean crop. Virus and mildew diseases have been observed in this species over many portions of the world. The specific causual virus observed in this study has not been identified, but it produced a leaf puckering, stunting, and flower abortion. These symptoms influenced the expression of a number of characters including days to flower, height, pods per plant, seeds per pod, and 1000-seed weight as well as yield. In this study, varieties M101 and M317 were the only parents having negative (resistance) general combining ability effects for the expression of virus symptoms. Thus progenies of crosses involving these two parents among those studied should offer the best opportunity to select

lines with improved virus resistance. Both M101 and M277 had significant general combining ability effects for resistance to mildew while M304 showed a negative general combining ability effect which was not significant. Crosses between these three lines should provide the best opportunity to select lines with improved resistance to mildew.

The rather limited results in this study indicated that considerable heterosis for yield and several other characters may be obtained in the F_1 mungbean hybrids, while others showed little or no heterosis. Since these data were collected from spaced planted plants, the amount of heterosis found for yield or any other character, may not give the same response in solid stands. Comparisons among hybrids and their respective parents need to be conducted under conditions similar to the conventional method used for evaluation of agronomic performance with nursery plots before critical evaluation of heterosis in mungbeans could be made.

The ultimate success of a new variety in practical agriculture depends on a variety of attributes, each contributing something to the complex interaction which determines success. The portion of the genetic variability which can be utilized is the additive portion, since this type of gene action can be retained in subsequent generations in self pollinated crops. From broad sense heritability analysis and estimated genetic advance values

utilizing 5 percent, 10 percent, and 20 percent selection intensity for six characters, it was indicated that improvements can be made for each character. The dramatic estimated increase at the lower selection intensities for each character was probably a function of the diverse nature of the parents utilized and of the lack of selection practiced heretofore in the parental and segregating hybrid populations. The frequency distribution tables (Appendix Tables 1-10) for each character give values and frequency for each individual observation. These results indicated that the highest 5-20 percent of the population (or the lowest 5-20 percent depending on the character in question) could result in increases of the magnitude indicated by the estimated genetic advance for each character.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This investigation was an evaluation of the parents and crosses among five mungbean varieties in 1971 and among three mungbean varieties in 1972. The objectives were (1) to obtain estimates of the predominate types of combining ability for each of ten characters studied, (2) to obtain heritability estimates for the ten agronomic characters investigated, (3) to determine the relationship between yield and the components of yield, and (4) to investigate the extent of heterosis present in crosses among the varieties of mungbean studied. The characters studied were yield per plant, number of pods per plant, number of seeds per pod, 1000-seed weight, number of days to first flower, number of days to first ripe pod, plant height, branch length, virus score, and mildew score. The parents were selected on the basis of their diverse plant characteristics and were assumed to have broad genetic divergence. Five parents in 1971, and the respective F_1 crosses among them, and three parents in 1972, and the respective F_1 and F_2 populations of crosses among them, were planted in randomized complete block designs with five replications in the two seasons. The data were subjected to a diallel analysis as described by Griffing (1956). General and

specific combining ability estimates were calculated for each character. Both midparent and high parent heterosis were measured on the 1971 data. Narrow sense heritability estimates were obtained on each character from the 1971 test while broad sense heritability estimates and pooled estimated genetic advance values were calculated from the 1972 three parent diallel.

Based on the data in these two experiments the following conclusions were made:

1. The yielding capacity of the mungbean plant is quantitatively inherited and is composed of morphological components which are also quantitatively inherited.

2. The major components of yield in the mungbean are number of pods per plant, number of seed per pod, 1000-seed weight, plant height, and branch length.

3. Both the diallel cross analysis and the simple phenotypic correlations indicated that the number of pods per plant had the greatest effect on yield.

4. A large portion of the total genetic variation associated with the yield components, number of pods per plant, number of seeds per pod, 1000-seed weight, plant height, and branch length was the result of additive gene action.

5. Specific combining ability effects were significant for part of the characters studied but were less important overall than the general combining ability effects.

6. With the large amount of positive general combining ability for plant height in variety M277 and the relative large amount of negative (shortness) general combining ability for branch length in varieties M299 and M304, phenotypic selection in crosses involving these parents may be useful in obtaining more desirable plant types.

7. Narrow sense, broad sense heritability estimates, and correlation values were in general agreement with the results of the diallel analyses and also indicated a sizeable portion of additive gene action for all characters studied.

8. Because of the divergent germ plasm base and lack of selection pressure on these populations, it is indicated that rapid genetic gain may be achieved for each character.

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APPENDIX

Appendix Table 1. Frequency distribution of parents, F_1's, and F_2's for yield in grams per plant (1972).

Population	Class center in grams													Total No. of plants	Mean*
	10	20	30	40	50	60	70	80	90	100	110	120	130		
Parents															
M101	1		1	2	5	7	4	5						25	60.4
M304	9	8	7	2										26	21.1
M317		5	9	1	1	4	1	1	1					23	37.7
F_1's															
101 x 304	8					1	4		1	3		1	1	19	69.7
101 x 317		1		3	5	3	11	5	1	1	2			32	71.0
304 x 317			1			2	6	4	2	3				18	75.3
F_2's															
101 x 304	7	5	15	16	22	28	27	12	7	3	1	3	2	148	58.1
101 x 317	13	8	13	13	15	13	10	7	4	3	1	1	1	102	51.8
304 x 317	12	9	18	26	18	22	17	3	1	1				127	46.6

*LSD at .05 level of probability = 16.2.

Appendix Table 2. Frequency distribution of parents, F_1's, and F_2's for number of pods per plant (1972).

Population	Class centers in number of pods													Total no. of plants	Mean*
	20	40	60	80	100	120	140	160	180	200	220	240	260		
Parents															
M101		1	7	9	6	2								25	83.6
M304	7	6	7	5	1									26	52.4
M317	2	9	5	3	1	3								23	59.3
F_1's															
M101 x M304				2	2	1	4	3	6	1				19	154.9
M101 x M317		1	5	8	14		2	1		1				32	103.3
M304 x M317			1		6	3	2	5					1	18	128.3
F_2's															
M101 x M304	10	7	21	40	32	18	11	4	3	2		1		148	93.2
M101 x M317	7	14	27	18	21	8	2	2	1					100	76.8
M304 x M317	7	10	17	30	33	18	7	2	2	1				127	90.9

*LSD at .05 level of probability = 18.4.

Appendix Table 3. Frequency distribution of parents, F_1's, and F_2's for number of seeds per pod (1972).

Population	Class centers in number of seeds													Total no. of plants	Mean*
	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5		
Parents															
M101							2	14	9					25	11.9
M304	2			1	3	2	6	1	2	8	1			26	11.2
M317							2	8	5	8				23	12.6
F_1's															
M101 x M304						1	1	5	6	6				19	12.4
M101 x M317								4	12	15	1			32	12.9
M304 x M317						2	2	4	3	5	2			18	12.8
F_2's															
M101 x M304		1			1	2	8	20	50	41	21	3	1	148	12.8
M101 x M317	1		1	1		4	13	25	39	15	1			100	12.0
M304 x M317	1	1		6	5	8	16	23	25	27	8	6	1	127	11.9

*LSD at .05 level of probability = 0.95.

Appendix Table 4. Frequency distribution of plants, F_1's and F_2's for 1000-seed weight (1972).

Population	Class centers in grams											Total no. of plants	Mean*
	38	43	48	53	58	63	68	73	78	83	88		
Parents													
M101						1	6	9	5	3	1	25	74.6
M304		4	4	2	11	4	1					26	54.8
M317			1		3	13	4	2				23	63.1
F_1's													
M101 x M304			1	2	5	7	2	2				19	59.4
M101 x M317			1		3	6	19	3				32	66.2
M304 x M317			3	3	4	4	3	1				18	58.9
F_2's													
M101 x M304		1	2	13	31	45	29	16	11			148	63.4
M101 x M317	4	3	3	9	12	18	17	16	13	3		98	64.3
M304 x M317	2	6	14	33	43	25	4					127	55.7

*LSD at .05 level of probability = 4.2.

Appendix Table 5. Frequency distribution of parents, F_1's, and F_2's for number of days to first flower in 1972.

Population	Class centers in days											Total no. of plants	Mean*
	40	45	50	55	60	65	70	75	80	85	90		
						Parents							
M101				2	14	8	1					25	61.4
M304				2	8	11	5					26	64.1
M317					11	11	1					23	63.4
						F_1's							
M101 x M304			1	4	10	4						19	57.6
M101 x M317					17	13	2					32	62.8
M304 x M317				8	3	6	1					18	59.2
						F_2's							
M101 x M304		3	1	19	68	43	10	2	2			148	61.3
M101 x M317		1		4	33	42	13	5	2	2		102	64.2
M304 x M317		1	5	12	55	40	13	1				127	61.5

LSD at .05 level of probability = 3.66.

Appendix Table 6. Frequency distribution of parnets, F_1's and F_2's for number of days to first ripe pod.

Population	Class centers in days											Total no. of plants	Mean*
	60	65	70	75	80	85	90	95	100	105	110		
Parents													
M101		1	4	8	8	2	2					25	81.1
M304		1	2	2	7	11	2	1				26	85.9
M317				2	4	7	8	2				23	85.7
F_1's													
M101 x M304			1	4	9	5						19	76.8
M101 x M317				5	6	16	4	1				32	83.1
M304 x M317			1	8	1	8						18	75.6
F_2's													
M101 x M304	1	1	13	38	23	39	27	2	1	3		148	81.2
M101 x M317		3	2	7	24	27	26	3	5	4		101	84.6
M304 x M317		5	8	21	27	25	36	4	1			127	82.0

*LSD at .05 level of probability = 4.41.

Appendix Table 7. Frequency distribution of parents, F_1's and F_2's for plant height (1972).

Population	Class centers in centimeters								Total no. of plants	Mean*
	30	40	50	60	70	80	90	100		
Parents										
M101	2	20	3						25	40.1
M304	5	14	7						26	40.8
M317	1	3	12	7					23	49.2
F_1's										
M101 x M304		14	4						18	44.0
M101 x M317			12	20					32	45.8
M304 x M317		1	15	2					18	52.3
F_2's										
M101 x M304	9	79	46	14					148	44.9
M101 x M317	5	36	43	13	2	1	1	1	102	48.4
M304 x M317	3	37	60	25	2				127	49.0

*LSD at .05 level of probability = 4.9.

Appendix Table 8. Frequency distribution of parents, F_1's and F_2's for branch length (1972).

Population	Class centers in centimeters								Total no. of plants	Mean*
	10	20	30	40	50	60	70	80		
Parents										
M101				9	13	3			25	46.2
M304		3	10	12	1				26	34.6
M317			1	9	13				23	44.4
F_1's										
M101 x M304			11	5	2		1		19	38.1
M101 x M317				15	16	1			32	46.4
M304 x M317			6	9	3				18	40.9
F_2's										
M101 x M304		6	27	69	41	5			148	41.2
M101 x M317	1	2	22	38	32	4	3		102	42.0
M304 x M317	1	3	26	50	43	4			127	41.7

*LSD at .05 level of probability = 5.2.

Appendix Table 9. Frequency distribution of parents, F_1's, and F_2's for virus score in 1972.

Population	Class centers in percent											Total no. of plants	Means*
	0	10	20	30	40	50	60	70	80	90	100		
Parents													
M101	25											25	0.5
M304		4	5	3	5	5	1		1	1		25	36.3
M317	12	7	3									22	7.3
F_1's													
M101 x M304	18		1									18	4.0
M101 x M317	32											32	1.0
M304 x M317	13	4										17	3.0
F_2's													
M101 x M304	140	2	2			3						147	2.0
M101 x M317	82	7	2	1			2	1	1	1		97	5.3
M304 x M317	84	27	7	3	1			2				124	6.6

*LSD at .05 level of probability = 9.08.

Appendix Table 10. Frequency distribution of parents, F_1's and F_2's for mildew score in 1972.

Population	Class centers for score of 1 to 5								Total no. of plants	Mean*
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5		
					Parents					
M101	14		11						25	1.8
M304	2		12		8		3		25	2.7
M317			11		11				22	2.7
					F_1's					
M101 x M304	9		9		1				19	2.0
M101 x M317	2		19		11				32	2.4
M304 x M317	6		11						17	1.6
					F_2's					
M101 x M304	11		104		29		1		145	2.4
M101 x M317	2		60		30		4		96	2.6
M304 x M317	4		56		63		1		124	2.7

*LSD at .05 level of probability = 0.72.

VITA

John Milton Yohe, son of John and Mamie Yohe was born on March 8, 1936, on a farm near Harrisonville, Missouri. He graduated from Harrisonville High School in 1954. He received the B.S. degree in Animal Husbandry from the University of Missouri in 1959. The Masters of Science degree was obtained in 1962 in the area of poultry nutrition from the University of Missouri, Department of Poultry Husbandry. From 1962 to 1969 the writer was employed in the feed manufacturing and animal health industry. Since 1969, he has been a research assistant at the University of Missouri, Department of Agronomy, while pursuing the Ph.D. degree.

The author is a member of Gama Sigma Delta, Sigma Xi, The American Society of Agronomy, The Crop Science Society of America, The Indian Society of Genetics and Plant Breeding, The Poultry Science Association, The Worlds Poultry Science Association, The American Society of Animal Science, and is an Elder in the Reorganized Church of Jesus Christ of Latter Day Saints.

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