RELATIONSHIPS AMONG KERNEL WEIGHT, PERCENTAGE

PROTEIN AND GRAIN YIELD

IN GRAIN SORGHUM

By

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CHAPTER I

INTRODUCTION

Breeding for improved protein content in the cereal grains has
gained much emphasis in this new era of agricultural technology. The
protein crisis is world wide and much has been done in almost all crops
to improve this important food constituent most especially to alleviate
malnutrition in some underdeveloped countries. However, until recently
the results of the efforts exerted by plant breeders on protein
improvement in cereal was far from satisfactory.

The development of high lysine content in corn opened a bright
hope for better protein quality. But still much work is needed to put
this new characteristic into better commercial utilization. For some
reason crops with high protein content do not produce as much grain.

Grain sorghum ranks fourth among the cereals in the world for
production (17). Grain yield was increased through hybridization.
Now the search for germplasm with better grain yield coupled with high
protein is beginning in grain sorghum.

The sorghum plant is among the most diverse of all cultivated
crops in the world. This implies that among the genus Sorghum, a very
wide genetic variability exists. These germplasm resources by the
initiative of man can be pooled and manipulated to form improved plant
populations out of which new and better gene combinations could be
extracted. recombined, and molded into better sorghum cultivars.

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Protein analyses of sorghum grains revealed a very wide genetic variability (13, 43). Protein content ranges from 6% to as high as 26% in the world collections. Protein content of the plant ranges from 10 to 30% (31). This makes the sorghum plant a better potential source of food for both human and animals.

Protein characteristics are said to be governed by many genes. Like grain yield, protein is one of the most complex characters to improve. Besides, most findings have revealed negative correlations between percent protein and grain yield. This inverse relationship between these characters presents a great challenge to plant breeders to improve both characteristics. Better selection of parents and a continuous search for better germplasm is expected to yield favorable results.

Another aspect that has been considered recently is kernel size. Larger kernels (seeds) are expected to contain more reserved food materials which affect seed germination and, likewise, affect plant growth, development and ultimately yield.

Today, farmers have become more and more aware of seed quality. Seed quality not only determines the commercial value of the grain but also its milling quality and utilization. It is for this relationship that breeding for kernel size, protein content, and grain yield is a challenging venture.

This study was, therefore, undertaken in order to:

1. assess the relationships between kernel weight and percentage protein and between kernel weight and grain yield,

2. develop hybrids superior in kernel weight (size), percentage protein and grain yield, and

3. relate other agronomic characters to kernel weight (size),
    percentage protein and grain yield.

CHAPTER II

LITERATURE REVIEW

Sorghum grain production and utilization has been increasing since the crop was domesticated. Numerous endeavors have been undertaken to utilize the wide genetic variability of sorghum to increase production and improve the nutritional quality and kernel size.

Some Findings Related to Kernel Size

Numerous types of investigations have been conducted to assess the contribution of kernel size to grain yield in sorghum, wheat, corn, and other crops. While kernel size was positively correlated with kernel weight on a 100-kernel basis, kernel size was negatively correlated with grain yield (4, 9, 39, 41, 44). Quinby and Schertz (53) pointed out that although variation in seed size is apparent and can be stabilized within varieties, genetic control of seed size is not understood. However, an inverse relationship between seed size and seed number apparently exists. They recommended that in a breeding program, progress toward large seed can be made as long as seed number is ignored.

Voigt, et al. (59) studied the inheritance of seed size in sorghum using large seed and small seed parents and analyzed the F_1 and F_2 generations and the first two backcrosses. They concluded that since heritability was slightly in excess of 60%, considerable progress in

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changing seed size by any method of breeding and selection based on additive genetic variance should be possible in the segregating populations. Genes controlling seed size in sorghum acted largely in an additive manner.

Malm (41) pointed out that selecting for seed size or head size was much more effective in improving productivity than selecting for seedling vigor. Large seeded parents showed the highest degree of general combination ability. Both general and specific combining ability effects were of importance in the expression of seed weight. The hybrids of the large seeded parents produced more than 50% more protein per hectare than the check hybrid.

Miller (44) found significant increases in seed size and seed weight when a large seeded male was crossed to medium seeded or small seeded females, but he found the lowest grain yield when large seeded varieties were used as female parents. In the same paper Miller (44) also found a highly significant positive correlation between seedling height and weight of 100 seeds.

Bremner, et al. (10) and Sage (54) pointed out that the dominating factor in seed-plant relationships in wheat was the extent of the energy source available to the developing seedlings. This in turn determined the size of the plant and the extent of the leaf surface at the time of exhaustion of the stored energy. At this time the seedling becomes wholly dependent on photosynthesis. Freeman (21) found that embryo size was shown to have negligible effect on growth. He pointed out that kernels of grain type sorghums usually weighed somewhere around 2.0 to 3.0 grams per 100 kernels although a range of 0.7 to 6.0 grams per 100 kernels has been observed in the world collections. The

mature endosperm consists of cells filled with starch and includes a single outside layer of cells called the aleurone layer (47). The region of cells containing a dense protein matrix lies beneath the aleurone.

<div align="center">
Some Studies Dealing with Percent

Protein in the Grain
</div>

Literature dealing with breeding for protein improvement in grain sorghum is limited compared with other crops. Wall and Blessin (60) and Deyoe and Shellenberger (15) reported that the types of protein in sorghum grains are albumin-soluble in water, globulin-soluble in solution of salt, glutelin-soluble in dilute alkali, and prolamine-soluble in ethyl alcohol. The albumin and globulin fractions include enzymes and other biological substances. Prolamines are predominant but are poor in nutritional quality because they are deficient in several essential amino acids. Glutelin is the second major protein fraction and it is intermediate in nutritional value.

The same authors further reported that the different parts of the sorghum grain differ in amount of protein. The prolamines are practically absent from the germ and hull but predominant in the endosperm. Germ protein is higher in nutritive value than the endosperm protein. The aleurone layer of endosperm is rich in albumin and globulins. The insolubility of most of the endosperm proteins and the manner in which these proteins bind the starch granules contributes to the difficulty of digesting sorghum grains.

According to Kersting, et al. (37) the percentage nitrogen decreased steadily in developing caryopses until 18 to 24 days after

pollination and remained quite constant thereafter. Absences of further percentage increases were probably due to the dilution effect of carbohydrate translocation. Quantities of nitrogen, total sugars, starch, and acid hydrolyzable carbohydrates were maximum at or near dates of maximum dry weight at about 33 to 44 days from anthesis.

An intensive study on improvement of protein quality and content was undertaken at Purdue University. Pickett (48) reported that there were several genes influencing protein and lysine levels and that both additive and nonadditive genes affected both protein and lysine as well as yield, and that protein and lysine can be incorporated into high yield. Of the 400 samples of the world collections screened for crude protein, they found protein variation of 7.4 to 25.9%.

Frey (22) reported that low protein percentage was completely dominant in corn and that the extreme state of dominance shown by the materials may be partially caused by hybrid vigor. Hayes and Garber (27) showed that hybrid vigor is more pronounced in the non-protein than in the protein portion of the kernel, thus tending to lower the protein percentage. East and Jones (18) concluded that low protein was partially dominant and governed by a large number of genes. The estimated minimum number of genes determining protein percentage in Illinois high and low protein strains of corn as calculated by the Castle-Wright formula was 22 pairs (22).

Pickett (48) also pointed out the work of Campbell which showed that soil nitrogen level could significantly influence the amount of protein but that the genetic effect was still much greater than the adjustment due to fertilization. It was also reported that an indication of genotype x location interaction for protein and lysine was

found. Wilson (63) in his literature review pointed out that grain protein is known to be influenced by a number of nongenetic factors such as soil type, fertilization, moisture, planting date and rate, and air and soil temperatures. Although the physiologic and genetic basis of protein production is still not fully understood, there is a universal agreement that protein production is genetically controlled but heavily influenced by environmental factors.

Protein Determination

Although the micro-Kjeldahl method is the most reliable method for nitrogen determination, the Udy dye-binding method is used because it is easy, fast and less expensive, thereby enabling plant breeders to screen a large number of samples of breeding materials (63).

According to Udy (57, 58) the wheat protein reacts with the disulfonic acid dye, orange G, at pH 2.2 to form an insoluble complex. The amount of dye bound per gram of sample may be used to provide an accurate estimate of protein content. In practice the estimate is based on the concentration of unbound dye, as measured colorimetrically using light filter (470 mμ).

Banasik and Gilles (6) found highly significant relationships from early tests between Udy and Kjeldahl methods. From their data, it appeared that the Udy protein analysis was consistently giving low values in the high protein range and overestimating protein contents in low areas. They pointed out that a protein content of 11.0% by the Kjeldahl would have a Udy value of 11.4% protein while a high level of Kjeldahl protein of 19.0% would show 18.2% protein by the Udy method.

Wilson (64) developed a grain sorghum conversion chart in order to

better correlate Udy colorimeter readings with Kjeldahl protein. His study indicated that fixed kernel composition was essential for good correlation of the dye-binding method with the Kjeldahl. When bran content of the sample was increased, the Udy method gave consistently higher determinations than the Kjeldahl method.

Fraenkel-Conrat and Cooper (20) pointed out that the number of protein groups binding with "Orange G" correspond well to the total number of basic (guanidyl, imidazole, amino) and acid groups (carboxyl, phenol, and thiol).

Combining Ability and Heterosis

Beil and Atkins (8) and Kambal and Webster (36) estimated the general and specific combining ability in F_1 hybrids for grain yield and its components in grain sorghum. They assumed that the differences in the general combining ability resulted primarily from the differences in the additive effects of genes, and that the differences in specific combining ability were due to differences in the nonadditive effects of genes. Both general and specific combining ability were of importance in the expression of grain yield, but specific combining ability effects were usually more stable than the general combining ability effects over the environment particularly for grain yield and seeds per head. The number of seeds per head was shown to be most likely related to yield and was not affected by the 100-seed weight. Likewise Niehaus and Pickett (46) pointed out that the general combining ability effects were high in the F_1 and F_2 but specific combining ability effects were high only in F_1. Number of seeds per head was the most important component of yield in the F_1 generation.

Henderson (29) was of the opinion that the most widely accepted genetic hypothesis to account for hybrid vigor was the dominant linked growth factor hypothesis and the theory of the cumulative action of divergent alleles. He said that of these two explanations, the dominant growth factor hypothesis has received the greatest acceptance. Jones (34) interpreted heterosis as an accumulation of favorable growth factors from both parents.

Kirby and Atkins (38) found that hybrids exhibited longer and wider leaves, earlier blooming, more seeds per head, more heads per plant, and larger seeds than their parents. Number of seeds per head was the character most highly associated with grain yield. Quinby and Karper (51) observed that first generation hybrids whose parents are distinct varieties are almost invariably vigorous and in many cases are tall in stature and late in maturity. Tall stature and lateness of maturity are due to the action of complementary genes. The large growth and high production of sorghum hybrids are due to combinations of complementary genes and heterosis. It is impossible to separate the effects of complementary gene action from those of heterosis. However, it is possible to develop hybrids that differ only in one allele. The size of the head is determined by the size of the growing point. A larger head frequently develops on a plant with 12 mature leaves than on one with 20. Reddy and Liang (52) pointed out that the higher yielding parents tended to produce greater genetic variability in the F_2 possibly because of the accumulation of desirable genes. Bartel (7) showed that hybrids had increased grain yield, plant height and number of leaves over their parents. The F_1 hybrids had kernels intermediate, equal, or larger in size than that of the large kernel parents. Atkins,

et al. (3) found correlation coefficients of 0.91 to 1.00 for the association of panicle weight with threshed grains. This indicated that unthreshed panicles may serve as an expedient and effective selection criterion for relative grain yield among a group of hybrids.

According to Blum (9) a significant and consistent effect of heterosis was found only in the number of grains per branch and mostly at the lower branches within the panicle. Node number per head and 100-kernel weight exhibited low heritabilities according to Fanous, et al. (19). Quinby (49, 50) pointed out that hybrid vigor does not increase leaf number but showed more in the grain than in the stover. Both the increase in the leaf blade, plant height, tillering, root and kernel size was attributed to hybrid vigor and it was assumed that this was due to hormonal differences between the hybrids and their parents. The same findings were reported by Liang (39), Kirby and Atkins (41), Chiang and Smith (11), and Kambal and Webster (35). Quinby (50) further suggested that faster cell division is believed to be the basis of heterotic manifestation in sorghum and that it was particularly effective in increasing cell number during the period following floral intiation when seed branches and spikelets were being formed.

According to Hageman, et al. (25) gene action which controls the major metabolic enzymes is usually intermediate between the homozygous parents in enzyme activity. Furthermore, it was assumed that the most likely explanation of the heterosis phenomenon rests in the fact that the hybrid between the two inbred parents is likely to have a better balanced metabolic system.

Assuming there is no overdominance, there appears a strong possibility that reciprocal selection would be superior to selection

for general combining ability as a consequence of either interaction
on non-allelic genes or repulsion phase linkages between certain loci
or both according to Comstock, et al. (12).

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Interrelationships Among Kernel Size

Protein Content, Grain Yield and

Other Agronomic Characters

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The most difficult aspect in breeding for increased kernel size,
protein content, and grain yield lies on the fact that they are
negatively correlated according to Wilson (63), Adamou (1), Balint (5),
Mukuru, et al. (45), Martin (42), Schaffert, et al. (55), and Kirby and
Atkins (38). Schaffert, et al. (55) suggested that the negative
correlation between grain yield and percent oil is an estimate of
embryo size, and a positive correlation between grain yield and kernel
weight indicated that as yield increased a smaller percent of the seed
was embryo. The fact that protein per seed was positively correlated
with percent protein and lysine as a percent of the sample and not
significantly correlated with grain yield, indicated that increased
protein per seed may be selected without a reduction in yield. Willcox
(62) stated that the inverse yield nitrogen law means that if two
kinds of plants are grown in the same environment, the one with the
smaller percentage of nitrogen will give larger yield of vegetable
substances per unit of soil surface. Put in another way it follows,
therefore, that the one with least nitrogen percentage will yield more,
regardless of botanical taxonomic position and regardless of genes
that may control secondary characters.

Mukuru, et al. (45) found that kernel weight or kernel volume were

significantly and negatively associated with days to flower, plant height, kernels per panicle and percent lysine of protein. Ayyangar, et al. (4) also found that kernel size was highly correlated with kernel weight, the larger the kernel, the bigger the embryo and the bigger the seedlings that grow from it. Liang, et al. (40) studied interrelations among agronomic characters in grain sorghum and found that grain yield was positively and significantly correlated with head weight,kernel number, and head number. Head weight and half bloom date may be considered the best indicators for yield, while germination percentage may be of value as an indicator for protein percentage. Furthermore, direct selection for protein may be more effective in improving protein content.

Diallel Cross and the Genetic Basis
of Agronomic Characters

According to Whitehouze, et al. (61) it is important to base assessment of individual crosses on their behavior in the early generations preferably the F_1 so that the crosses having a low probability of producing high yielding lines can be discarded. In this regard analysis of a diallel set of crosses may enable predictions to be made from the information collected in the F_1.

Griffing (24), Hayman (28), Jinks (32), Crumpacker and Allard (14) and Hill (30) suggested the following conditions for diallel crosses; the mechanism of inheritance must be diploid; the maternal effect must be absent; the parents to be used must be homozygous; there should be no interaction between genes at different loci; no multiple alleles should be present; and the genes must be randomly distributed among the parents.

Dickson and Jinks (16) presented a generalized analysis of diallel crosses and pointed out that this type of analysis provided an estimate of the over all degree of dominance, of the inbreeding coefficient or degree of heterozygosity of loci showing dominance and of the allele frequency at such loci. Whether dominants or recessives are in excess can also be determined. In practical application of the analysis, it is necessary that the conditions should be stated explicitly; the parents contribute equal samples of gametes to each family. With homozygous parents no problems arise, but with parents heterozygous at any locus there would be problems. Jinks (33) reported that data of a number of diallel crosses analyzed by methods which can discriminate between heterosis arising from interaction between non-allelic genes showed that: dominance is always associated with non-allelic inter-action;specific combining ability is always associated with the presence of non-allelic interaction while general combining ability is the outcome of uncomplicated dominance.

According to Allard (2) heritable differences between the homozygous parents in the absence of non-allelic interaction must result from the additive effects of genes. Hence parental lines differing significantly from each other must carry genes with different additive effects. Constancy of the additive components of variation can be detected unambigously by the parents x environment interaction of the analysis of variance of parents. Significance provides evidence that they interact with the environment and nonsignificance is suggestive of the constancy of the additive effect under different evironment and nonsignificance is suggestive of the consistancy of the additive effect under different environmental conditions.

Gilbert (23) suggested that even if we accept the genetical assumption and the statistical method employed, it is hard to know which plants contain which genes. He concluded that the diallel cross offers a means of rationalizing some aspects of plant breeding while keeping the amount of work down to a manageable level. Its utility to the breeder can be exaggerated. The performance of the parental varieties themselves gives valuable prediction of the relative behavior of the crosses, but the diallel cross does give further information.

CHAPTER III

MATERIALS AND METHODS

Parent Lines

Eight inbred lines were selected as the parents in a diallel crossing system excluding reciprocals. The eight parents were classified on the basis of kernel weight and protein content (Table I).

TABLE I

CLASSIFICATION OF PARENTS USED IN A DIALLEL CROSS

Parent No.	Kernel Size		Protein Content		Pedigree
1	Very large grain	(VG)	High	(H)	R-K x Korgi^{2}E-1-1-1-1-1
2	Very large grain	(VG)	Low	(L)	IS 3579c Temp. Bk.
3	Large grain	(LG)	High	(H)	ROKY 39
4	Large grain	(LG)	Low	(L)	Wheatland
5	Medium grain	(MG)	High	(H)	A-Wheatland-Collubi x ROKY 7-2-2-2-1
6	Medium grain	(MG)	Low	(L)	Redlan
7	Small grain	(SG)	High	(H)	Bonar-Day x #1-7-1-2
8	Small grain	(SG)	Low	(L)	BOK 8

R-K is a cross between Redlan, an Oklahoma variety and Kaura, an introduction from Nigeria. Korgi is an introduction from Sudan. Parent 1 has yellow kernels, is awnless and grows to a height of 80 to 90 cm. IS 3579c Temp Bk came from the sorghum conversion program. A bulk was made of several plants selected from early backcrosses, but with temperate adaptation. This seed was distributed from Texas and a selection from this bulk grown in Oklahoma was used as one parent in the diallel. It has white kernels, is awnless and grows to a height of about 90 to 100 cm. ROKY 39 is a restorer line released by the Oklahoma station. It has red kernels, is awnless and grows to a height of about 80 to 90 cm. Wheatland is a released variety with red kernels. It is awnless and grows to a height of 80 to 90 cm. A Wheat-Collubi x ROKY 7 is an experimental line in an advanced generation. It has brown kernels, is awnless and grows to a height of 80 to 90 cm. Redlan is a released variety with red kernels. It is awnless and grows to a height of 80 to 90 cm. Bonar-Day x #1 is an experimental line in advanced generation. It has brown kernels, is awned and grows to a height of 80 to 90 cm. BOK 8 is a released variety with red kernels. It is awnless and grows to a height of 80 to 90 cm.

Emasculation and Crossing

Seeds of each of the eight parents were sown in ten or more pots in the greenhouse at the Agronomy Research Station of the Oklahoma State University in December of 1974 and 1975. The seedlings were watered, fertilized, and thinned to two plants per pot to prevent overcrowding.

At the start of anthesis 50 or more florets of selected female parents were hand emasculated by the use of forceps. The emasculated

florets were then covered to prevent contamination. Hand pollination
was done one to four days after emasculation by collecting pollen from
male parents with the use of shallow dishes and applying the pollen to
the receptive stigmas with a small brush. Pollinated florets were
covered with glassine bags. Stigma receptivity is readily indicated
by the apparent opening of the emasculated florets. Male parents were
determined by kernel size, so that smaller kernel size was always the
female parent in a cross regardless of the protein content. Three to
five female plants were emasculated for each cross in order to get
adequate F_1 seeds.

During December 1975, remnant F_1 seeds produced by hand emascula-
tion in the preceeding winter were also planted in the greenhouse to
produce backcrosses. Due to the lack of F_1 seeds in some crosses only
26 backcrosses were made. Kernel size and protein content determined
the male parent, so that the larger kernel size and the higher protein
line always became the pollen parent whenever possible.

Field Experiments

Both the F_1 and the BC seeds were sown in six peat moss pots per
entry per replication inside the greenhouse. As soon as the seedlings
were big enough they were transplanted into a randomized block design
with four replications at the Perkins Agronomy Research Station. Each
Entry was put in a row three meters long, spaced one meter apart with
the seedlings transplanted 30 cm apart in the row. Two border plants
at opposite ends of each row were sown in advance so that at trans-
planting time they were similar in size to the experimental plants.
The transplants were watered until the were established.

A preplant application of fertilizer consisting of 133 kg N/ha and 114 kg K_2O/ha were broadcast on all experiments. The plants were fertilized with a sidedressing of ammonium nitrate at the rate of 40 kg N/ha two weeks before anthesis.

The sorghum heads were bagged before anthesis to ensure selfing and to protect the heads from insects and bird depredation.

At harvest, notes were recorded for individual plant for height, plant color, kernel color, and for the presence of awns.

The harvested heads were air dried for about one month or more in the greenhouse. Then after head weight was taken, the grain was threshed from the heads and weighed.

A similar procedure for the field experiment of the F_2 was followed in 1976 except that the seeds were sown by a grain drill and the row lengths were 8.5 meters. The seedlings were thinned to 15 cm apart. Only five heads were harvested at random per entry from which data were collected.

Laboratory Procedure

The protein contents of all materials in this study were determined employing the Udy dye-binding procedure and following the modified method by Wilson (64).

A representative grain sample, consisting of five grams or more from each head, was hand cleaned to remove foreign materials and badly shrunken or diseased kernels. Each sample was ground to a particle size of 0.015 mm using a Weber cyclone hammermill equipped with a vacuum collecting device. After the ground samples were blended, one gram subsamples were taken for protein determinations.

Each one gram subsample was placed in a two-ounce reaction bottle and 40 ml of the standard reagent dye which was obtained from the Udy Analyzer Company was added. The reaction bottles were then placed on an Eberbach shaker and shaken vigorously for two hours. The shaker will hold 44 bottles at a time.

The colorimeter required one to two hours warm-up period after which it was adjusted to 42% light transmission by using standard reference dye. The colorimeter was equipped with a flow-through cuvette which allows rapid and continuous operation.

At the end of the two-hour period of shaking time, the sample solution was filtered into the cuvette through a funnel equipped with a fiber glass filter disc. Percent light transmission was taken when the colorimeter needle had stabilized after approximately 30 seconds. The light transmission readings were converted to percent protein using the standard grain sorghum conversion chart prepared by Wilson (64).

Data Collected

Three to four F_1 and BC plants were used from each replication for data collection, and five random plants were used from each replication for the F_2 populations. The following data were recorded:

1. Heading date (HD) -- number of days from planting to head exsertion which also corresponded to the time of bagging of the sorghum head.

2. Plant height (HT) -- a measurement from the base of the plant to tip of the panicle immediately before harvest.

3. Head weight (HW) -- weight of the individual panicle taken after air drying.

4. Grain weight or Grain yield (GY) -- weight of grains per head after threshing.

5. Weight of 100 kernels (KW) -- weight of 100 kernels that were hand cleaned, counted by a vacuum counter, and weighed by Torsion balance. It will be refered as kernel weight henceforth.

6. Percentage protein (%P) -- a determination made from the ground samples of grain from each head by the Udy dye-binding method.

7. Threshing percentage (%T) -- a figure determined by dividing grain weight by head weight and multiplying by 100.

8. Kernel number (KN) -- the total number of kernels per head as determined by dividing grain yield by the weight of 100 kernels and multiplying by 100.

9. Protein yield (PY) -- the total protein production in grams per plant estimated by multiplying grain yield by percent protein and dividing by 100.

Statistical Procedure

Standard analyses of variances of the randomized block design for all the data collected were done by years and generation. The eight parents were analyzed separately from the F_1, F_2 and backcross generations. The means of each entry were tabulated and least significance difference (LSD) estimates were calculated for each variable.

Agronomic character correlations were also calculated and estimates of coefficient of correlations for the traits were tested using F ratios at .05 and .01 level of probability based on two independent variables.

Graphs depicting the performance of each of the eight parent's respective hybrids were constructed on the basis of grain yield, kernel number, and protein percentage to show the relationship of these variables.

Percentage heterosis for each of the 28 hybrids was also calculated based on the mean deviation from the midparent and high parent. The formulae for these estimates are as follows:

$$\% \text{ Heterosis as deviation from midparent} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\% \text{ Heterosis as deviation from high parent} = \frac{\overline{F_1} - \overline{HP}}{\overline{HP}} \times 100$$

The data of F_1's and their parents of the diallel crosses were also subjected to combining ability analyses using Griffing's Method I and Model II (24). The general combining ability estimates were then separately evaluated as well as their corresponding specific combining ability estimates. Differences within effects were tested by the appropriate F ratios. Standard errors for these effects were also calculated. Components of variances for the desired characters were calculated and the ratios of the general combining ability over that of the specific combining ability were also estimated in order to ascertain the relative importance of the additive and nonadditive gene actions for the characters under consideration.

Since none of the assumptions necessary for a valid Jink's-Hayman diallel analysis were met, the procedure was not attempted.

CHAPTER IV

RESULTS AND DISCUSSION

Performance of Parents and Their Hybrids

The performance of the eight parents and 28 hybrids (derived from them by a diallel system of crossing, excluding reciprocals) was measured in terms of nine agronomic variables, namely: days from planting to heading (HD), plant height (HT), head weight (HW), grain yield (GY), kernel weight (KW), kernel number (KN), percentage threshing (%T), percentage protein (%P), and protein yield (PY). The analyses of variance of these variables for parents and hybrids are presented in Tables II and III, respectively. Significant ($P < .05$) parent x year interactions (Table II) were found for the variables GY, KW, and %T, and significant ($P < .01$) parent x year interactions were observed for HD and %P, suggesting that the parent did not perform similarly in the two years. The interactions for HT, HW, KN, and PY were not significant indicating that the parents performed similarly in the two years. Significant ($P < .05$) hybrids x year interactions (Table III) were found for HD, %P, and KN and significant ($P < .01$) hybrids x year interactions were found for HT, HW, and KW. There were no significant hybrid x year interactions for GY, %T, and PY suggesting that these variables performed similarly in the two years.

TABLE II

ANALYSES OF VARIANCE OF THE DIFFERENT AGRONOMIC
VARIABLES OF THE EIGHT PARENTS

Source	df	HD	HT	HW	GY	KW	%T	%P	KN	PY
Year	1	166.06	3009.78	1739.83	2568.59	13.47	4310.64	2.19	252541.32	34.60
Rep x year	6	6.40	5.16	51.82	37.70	0.20	148.02	1.15	62322.97	0.45
Parent	7	46.45**	538.67**	1229.97**	585.52**	7.40**	313.96	13.35**	2262630.80**	5.03**
Parent x year	7	9.89**	51.47	257.13	249.32*	0.48*	420.79*	3.44**	200735.01	2.21
Error	42	2.93	28.28	133.71	87.66	0.16	186.79	0.50	147653.61	1.15

*,** = Significant at .05 and .01 levels of probability, respectively.

TABLE III

ANALYSES OF VARIANCE OF THE DIFFERENT AGRONOMIC
VARIABLES OF THE F_1 HYBRIDS

Source	df	HD	HT	HW	GY	KW	%T	%P	KN	PY
Year	1	732.83	24097.16	46813.39	38241.52	112.66	10741.05	6.39	1895738.33	485.30
Rep x year	6	7.37	55.04	323.00	88.01	0.34	79.54	1.13	106061.99	1.26
Hybrid	27	44.57**	2089.81**	3172.53**	1498.07**	2.32**	231.69**	6.22**	2975216.83**	15.70**
Hybrid x year	27	8.95*	188.85**	386.49**	292.65	1.17**	276.65	1.49*	379389.64*	3.78
Error	162	4.93	61.98	181.19	249.65	0.13	224.06	0.84	222610.24	2.84

*,** = Significant at .05 and .01 levels of probability, respectively.

The data of the nine agronomic variables for the eight parents are presented in Table IV. Parent 6 was the latest to reach heading. It had the highest plant height, the heaviest head weight, and the most grain yield in 1975 and in the average of the two years. These superiorities were significant (P <.01) when compared to most of the parents. Parent 8 was the earliest to reach heading, and it was the shortest in plant height in 1975 and in the average of the two years. The lowest yielder in the two-year average was parent 1. Parent 7 produced the lowest kernel weight and the highest corresponding number of kernels in 1975 and in the two-year average with significant differences compared to the other parents except 5, 6, and 8. Parents 1 and 2 produced significantly (P <.01) larger kernels than the other parents in 1975 and in the average of 1975 and 1976. Parents 1 and 2 produced less than 6 and 7 only. The entries were selected for the study on the basis of kernel size and protein content. The first two entries had very large kernels, the second two entries had large kernels, the third two entries had medium kernels, and the last two entries had small kernels. For protein, the odd numbered parents had high protein and the even numbered parents had low protein. The kernel weight data (measure of kernel size) reflected these differences, although the magnitude of difference was not great nor significant. Parent 3 appeared to give the highest threshing percentage in 1975 and in the two-year average. It also appeared that parents 1 and 5 contained the highest protein percentage in 1975 and in the average of the two years. They were significantly (P <.05) higher than most of the other parents. The highest protein yield per head was shown by parents 6 and 7 in 1975 and in the two-year average. Parents 1 and 8 yielded the least protein in

TABLE IV

MEAN PERFORMANCE BY YEARS OF EIGHT PARENTS
USED IN A DIALLEL CROSS

Variable	Parent								Mean	LSD	
	1	2	3	4	5	6	7	8		.05	.01
1975											
HD (days)	60.1	57.5	57.8	61.1	60.8	63.0	60.0	55.6	59.5	0.78	1.06
HT (cm)	94.1	88.7	93.8	85.0	91.1	112.4	87.1	79.4	91.5	5.23	7.12
HW (g)	29.1	46.5	40.9	60.0	46.1	77.5	54.2	43.4	49.7	11.40	15.52
GY (g)	19.5	36.5	33.1	37.3	20.7	54.3	41.0	26.0	33.5	13.64	18.56
KW (g/100)	4.9	5.0	3.5	3.5	2.7	2.8	2.0	2.8	3.4	0.34	0.46
KN	396.0	750.0	935.0	1076.0	770.0	1956.0	2009.0	920.0	1104.0	453.59	617.15
%T	69.1	77.2	81.7	61.6	44.3	69.9	76.9	59.4	67.5	26.50	36.06
%P	14.1	11.7	13.1	11.0	14.6	10.2	12.8	11.7	12.4	0.84	1.14
PY (g)	2.7	4.3	4.4	4.1	3.0	5.5	5.3	3.0	4.0	1.65	2.25
1976											
HD (days)	54.3	52.8	56.9	58.5	55.9	59.3	57.8	52.1	56.2	3.47	4.73
HT (cm)	80.8	72.4	77.5	68.7	83.2	91.6	73.5	74.5	77.8	9.74	13.26
HW (g)	27.2	25.9	34.2	60.0	46.6	46.8	47.8	25.8	39.3	21.18	28.81
GY (g)	13.8	11.3	18.2	35.2	25.7	26.7	25.2	10.7	20.9	13.89	18.91
KW (g/100)	4.1	3.1	3.0	2.7	2.2	1.8	1.6	1.4	2.5	0.75	1.02
KN	331.0	379.0	587.0	1373.0	1170.0	1555.0	1662.0	765.0	978.0	685.07	895.36
%T	50.8	52.7	52.2	57.4	55.0	57.0	51.9	41.5	51.1	10.27	13.98
%P	14.7	14.2	12.8	10.6	12.7	11.1	13.3	12.8	12.8	1.21	1.65
PY (g)	2.0	1.6	2.3	3.7	3.2	3.0	3.3	1.4	2.3	1.50	2.04

TABLE IV (CONTINUED)

Variable		Parent							Mean	LSD	
	1	2	3	4	5	6	7	8		.05	.01
Both Years											
HD (days)	57.2	55.1	57.4	59.8	58.3	61.2	58.9	53.8	57.9	1.68	2.20
HT (cm)	87.4	80.6	85.6	76.9	87.1	102.0	80.3	76.9	84.6	5.21	6.85
HW (g)	28.2	36.2	37.6	60.0	46.3	62.1	51.0	34.6	44.5	11.33	14.89
GY (g)	16.6	23.9	25.7	36.2	23.2	40.5	33.1	18.3	27.2	9.18	12.06
KW (g/100)	4.0	4.0	3.3	3.1	2.4	2.3	1.8	2.1	2.9	0.39	0.51
KN	364.0	564.0	770.0	1225.0	970.0	1755.0	1836.0	843.0	1041.0	376.56	494.87
%T	60.0	60.0	67.0	59.5	49.6	63.4	64.4	50.5	59.3	13.39	17.60
%P	14.4	13.0	12.9	10.8	13.6	10.7	13.0	12.3	12.6	0.69	0.91
PY (g)	2.4	2.9	3.3	3.9	3.1	4.2	4.3	2.2	3.2	1.05	1.38

1975 and in the two-year average. Since the parents were selected
as described above, an interesting comparison of pairs of parents for
kernel weight (size) and for percent protein can be made. Parents 1
and 2 were larger than 3 and 4 and parents 3 and 4 were larger than 5
and 6, and parents 5 and 6 were larger than 7 and 8 for both years and
for the average of the two years. Furthermore, for percentage protein,
parent 1 had a higher percentage than parent 2, parent 3 had a higher
percentage than parent 4, and so on through all the comparisons in
both years and in the two-year average. Although these differences
were not always significant, they were consistent.

From the analysis there was no significant interactions for parent
x year for HT,HW, KN, and PY. Therefore, the data on these characters
of the parents can be evaluated in the two-year average. Parent 6 was
tallest and parents 4 and 8 were shortest. Parent 6 had the highest HW
and parent 1 had the lowest. For KN parent 7 had a very large number
of very small kernels, while parent 1 had a very small number of very
large kernels. And finally the grain yield is a very important
component for PY, so that parents 4, 6, and 7 had high PY yield and
parents 1 and 8 were low.

In the means of all parents it is apparent that the plants
performed better in 1975 than in 1976 for all characters except protein
percentage. The higher protein percentage in 1976 does not indicate
a better season, because the plants were affected by drought and green-
bug damage.

The data on performance of the 28 F_1 hybrids derived from the
eight parents are shown in Tables V, VI, and VII. The latest to reach
heading among the hybrids was 7 x 6 in both years and in the two-year

TABLE V

MEAN PERFORMANCE OF THE F_1 GENERATION OF 28
CROSSES DERIVED FROM EIGHT PARENTS
(PERKINS, OKLAHOMA, 1975)

F_1 Hybrids	HD (days)	HT (cm)	HW (g/plt)	GY (g/plt)	KW (g/100)	KN (per head)	%T (%)	%P (%)	PY (g/plt)
2 x 1	56.3	151.5	98.3	51.5	5.9	898	56.5	11.0	5.7
3 x 1	55.5	114.2	111.6	58.5	5.0	1182	54.1	12.3	7.3
4 x 1	57.6	111.3	75.4	61.0	4.0	1352	82.7	12.4	7.6
5 x 1	59.4	108.5	74.5	53.3	3.6	1464	72.4	13.0	7.0
6 x 1	59.9	136.7	93.3	69.8	4.6	1511	74.5	12.0	8.3
7 x 1	62.3	117.0	120.6	86.3	3.4	2577	71.9	11.2	9.7
8 x 1	55.0	111.9	65.3	41.0	4.0	1039	63.6	12.5	5.2
3 x 2	56.9	114.6	73.1	56.0	4.3	1272	78.6	12.7	7.0
4 x 2	57.0	133.8	96.0	42.9	4.5	977	44.8	9.9	4.1
5 x 2	57.1	151.9	98.0	59.4	4.4	1362	62.9	10.6	6.3
6 x 2	58.1	145.7	105.2	80.1	4.3	1872	76.0	10.3	8.2
7 x 2	60.8	127.4	61.8	48.7	2.7	1819	82.1	12.2	5.9
8 x 2	54.2	124.5	97.1	79.1	4.1	1912	81.5	10.8	8.5
4 x 3	57.3	92.6	77.1	57.6	3.9	1490	74.0	11.7	6.7
5 x 3	57.8	99.2	59.1	32.7	3.0	1107	55.4	14.8	4.8
6 x 3	59.1	106.2	97.6	52.7	3.8	1374	55.1	11.1	5.8
7 x 3	58.9	101.0	102.4	73.0	2.8	2674	71.7	10.8	7.9
8 x 3	56.2	97.6	76.9	51.3	3.5	1476	66.6	11.7	6.0
5 x 4	59.4	93.0	74.3	47.3	3.0	1576	62.9	13.3	6.2
6 x 4	62.8	95.7	93.1	65.6	3.4	1945	69.6	10.3	6.7
7 x 4	61.5	92.0	104.6	79.3	3.0	2688	76.2	11.2	8.8
8 x 4	57.7	86.4	72.0	44.6	3.3	1327	60.9	12.0	5.3
6 x 5	61.2	111.9	109.5	72.7	2.9	2512	65.7	12.1	8.7
7 x 5	60.7	105.9	127.7	68.3	3.0	2294	54.5	11.6	7.8
8 x 5	56.7	95.3	71.6	51.9	2.8	1820	72.0	12.2	6.2
7 x 6	64.3	109.2	127.1	83.4	2.4	3526	64.7	11.6	9.4
8 x 6	56.9	98.4	74.5	56.6	3.0	1889	76.6	11.2	6.3
8 x 7	60.7	97.0	106.6	76.6	2.6	2969	72.4	11.0	8.4
Mean	58.6	111.8	90.9	60.8	3.6	1782	67.8	11.7	7.0
LSD									
.05	1.54	12.95	18.84	26.94	0.33	708.61	27.31	1.00	2.87
.01	2.02	17.02	24.76	35.41	0.43	931.36	36.00	1.31	3.78

TABLE VI

MEAN PERFORMANCE OF THE F_1 GENERATION OF 28
CROSSES DERIVED FROM EIGHT PARENTS
(PERKINS, OKLAHOMA, 1976)

F_1 Hybrids	HD (days)	HT (cm)	HW (g/plt)	GY (g/plt)	KW (g/100)	KN (per head)	%T (%)	%P (%)	PY (g/plt)
						Variables			
2 x 1	58.3	131.0	59.7	34.1	2.7	1242	56.3	11.7	3.9
3 x 1	55.8	83.3	47.1	23.4	3.2	745	50.4	13.6	3.2
4 x 1	53.9	85.8	60.4	31.4	2.5	1256	52.1	11.6	3.6
5 x 1	56.3	75.2	38.1	21.1	2.4	882	54.1	12.9	2.8
6 x 1	57.8	91.9	51.9	27.9	2.0	1432	54.2	11.7	3.3
7 x 1	59.1	100.5	113.6	67.1	2.6	2551	56.4	11.2	7.4
8 x 1	51.3	93.2	48.4	25.5	2.0	1300	52.5	12.6	3.2
3 x 2	52.9	101.8	58.1	32.6	2.3	1430	55.0	13.4	4.2
4 x 2	54.8	92.8	55.9	27.3	2.1	1381	48.3	11.1	3.0
5 x 2	50.8	115.6	69.8	39.0	2.4	1718	55.8	12.5	4.8
6 x 2	51.9	121.6	68.1	38.4	1.9	2024	55.6	11.3	4.3
7 x 2	56.0	100.8	39.8	15.9	1.6	1262	39.1	14.2	2.2
8 x 2	51.3	110.8	55.8	30.3	1.9	1590	52.9	11.6	3.5
4 x 3	56.1	73.0	57.7	32.1	2.7	1177	54.1	12.4	3.9
5 x 3	56.8	75.1	34.8	17.2	2.5	701	49.9	13.8	2.4
6 x 3	53.7	88.4	69.9	40.8	2.4	1691	53.7	11.8	4.7
7 x 3	55.7	87.6	75.0	40.6	1.8	2285	55.7	12.1	4.8
8 x 3	54.8	72.2	37.1	19.1	1.9	1053	51.8	12.1	2.3
5 x 4	53.5	81.7	56.9	32.8	2.7	1215	57.3	11.5	3.8
6 x 4	57.9	84.6	67.7	44.5	2.4	1831	65.2	11.4	5.1
7 x 4	59.9	83.1	88.6	53.2	2.2	2463	60.1	11.1	5.9
8 x 4	53.3	74.6	45.7	23.4	1.8	1291	51.4	12.0	2.8
6 x 5	53.9	93.7	67.9	35.4	1.7	1961	50.6	12.7	4.4
7 x 5	55.8	91.9	102.8	62.8	2.2	2842	61.1	11.4	7.2
8 x 5	50.9	80.9	43.1	18.3	1.7	1221	42.7	12.4	2.2
7 x 6	60.6	103.2	126.3	82.9	2.4	3413	65.7	11.0	9.1
8 x 6	53.7	82.9	43.8	25.4	1.8	1405	55.8	10.7	2.7
8 x 7	54.6	72.9	50.7	27.3	2.0	1393	51.5	11.2	3.0
Mean	55.0	91.1	62.0	34.6	2.2	1598	54.0	12.0	3.1
LSD									
.05	4.07	8.39	18.47	15.27	0.64	594.16	10.71	1.49	1.62
.01	5.35	11.02	24.28	20.06	0.84	780.85	14.07	1.96	2.13

TABLE VII

MEAN PERFORMANCE OF THE F_1 GENERATION OF 28
CROSSES DERIVED FROM EIGHT PARENTS
(AVERAGE OF TWO YEARS, PERKINS,
OKLAHOMA)

F_1 Hybrids	HD (days)	HT (cm)	HW (g/plt)	GY (g/plt)	KW (g/100)	KN (per head)	%T (%)	%P (%)	PY (g/plt)
2 x 1	57.3	141.3	79.0	42.8	4.3	1070	56.4	11.4	4.8
3 x 1	55.6	98.8	79.3	41.0	4.1	963	52.3	12.9	5.2
4 x 1	55.7	98.6	67.9	46.2	3.5	1304	67.4	12.0	5.6
5 x 1	57.8	91.9	56.5	37.2	3.0	1173	63.2	13.0	4.9
6 x 1	58.9	114.3	72.6	48.9	3.3	1471	64.3	11.8	5.8
7 x 1	60.7	108.7	117.1	76.7	3.0	2564	64.2	11.2	8.6
8 x 1	53.1	102.6	56.8	33.7	3.0	1169	58.1	12.6	4.2
3 x 2	54.9	108.1	65.6	44.3	3.3	1351	66.8	13.1	5.6
4 x 2	55.9	113.3	75.9	35.1	3.3	1179	46.5	10.5	3.6
5 x 2	54.0	133.7	83.9	49.2	3.4	1540	59.3	11.6	5.6
6 x 2	55.0	133.7	86.7	59.3	3.1	1948	65.9	10.8	6.3
7 x 2	58.4	114.1	50.8	32.3	2.1	1540	60.6	13.2	4.1
8 x 2	52.8	117.6	76.5	54.7	3.0	1751	67.2	11.2	6.0
4 x 3	56.7	82.8	67.5	44.9	3.3	1333	64.1	12.1	5.3
5 x 3	57.3	87.2	46.2	25.0	2.7	904	52.7	14.3	3.6
6 x 3	56.4	97.3	83.7	46.8	3.1	1532	56.3	11.4	5.2
7 x 3	57.3	94.3	88.7	56.8	2.3	2480	63.0	11.4	6.3
8 x 3	55.2	84.9	57.0	35.2	2.7	1265	59.2	11.9	4.1
5 x 4	56.5	87.3	65.6	40.1	2.8	1395	60.1	12.4	5.0
6 x 4	60.3	90.2	80.4	55.1	2.9	1888	67.4	10.8	5.9
7 x 4	60.7	87.6	96.6	66.3	2.6	2576	68.2	11.1	7.4
8 x 4	55.5	80.5	58.8	34.0	2.6	1309	56.2	12.0	4.0
6 x 5	57.5	102.8	88.7	54.1	2.3	2236	58.2	12.4	6.5
7 x 5	58.3	98.9	115.3	65.5	2.6	2568	57.8	11.5	7.5
8 x 5	53.8	88.1	57.4	35.1	2.2	1511	57.4	12.3	4.2
7 x 6	62.3	106.2	126.7	83.1	2.4	3470	65.2	11.3	9.3
8 x 6	55.3	90.6	59.2	41.0	2.4	1647	66.2	10.9	4.5
8 x 7	57.6	84.9	78.6	51.9	2.3	2181	62.0	11.1	5.7
Mean	56.8	101.4	76.4	47.7	2.9	1690	60.9	11.9	5.5
LSD									
.05	2.18	7.71	13.19	15.48	0.36	462.37	14.67	0.90	1.65
.01	2.86	10.14	17.34	20.35	0.47	607.66	19.28	1.18	2.17

average. The ranges in heading dates of the 28 hybrids were from 54.3 to 64.3 days in 1975, from 50.8 to 60.6 in 1976, and in the two-year average from 52.8 to 62.3 days. The earliest to reach heading in the two-year average was cross 8 x 2 followed by cross 8 x 1. There were significant (P <.01) differences among heading dates for many comparisons in both years.

Plant heights ranged from 92.0 cm to 151.9 cm in 1975 and from 72.2 to 131.0 cm in 1976. Taking the average values of the two years of data, the range in plant height was from 80.5 to 141.3 cm. Also in the average, the highest plant height was 141.3 cm for the hybrid 2 x 1 followed by 5 x 2 and 6 x 2 both with a height of 133.7 cm. The shortest hybrids were 8 x 4 and 4 x 3 with values of 80.5 and 82.8 cm, respectively. Many of the annual and average plant heights were significantly (P < .05) different from each other.

The range in head weights over the two years of data was from 46.9 to 126.7 grams while grain yield ranged from 25.0 to 83.1 grams for the same hybrids, 5 x 3 and 7 x 6, respectively. The 1975 planting gave higher head and grain weights because of drought and greenbug damage in 1976. However, it was observed that crosses which gave higher head weights and grain yields in 1975 also gave consistently higher head weights and grain yields compared to other hybrids in 1976. The differences were significant (P <.01) in many comparisons for both head weights and grain yields.

Kernel weights were higher in 1975 than in 1976 probably due to greenbug damage in the 1976 season. However, it was observed that hybrids had as large or larger kernel size than the smaller kerneled parents in all comparisons in 1975 and in the two-year average, and in

most comparisons in 1976 data. The range in kernel weight was from

2.4 to 5.9 grams in 1975 and from 1.6 to 3.2 in 1976. Larger kernel

size were observed from hybrids derived from parents 1 and 2, and many

of these hybrids were significantly (P <.01) larger than the rest of

the entries. In the two year average, the hybrid with the largest

kernel size was 2 x 1 followed by 3 x 1 while the hybrid with the

smallest kernel size was 7 x 2.

The number of kernels per head is generally affected by kernel

size and threshing percentage. It was observed that the hybrids with

larger kernels had fewer kernels per head, and the hybrids with smaller

kernels had more kernels per head. The number of kernels ranged from

898 to 3526 in 1975 and from 701 to 3413 in 1976. In the two-year

average cross 7 x 6 gave the highest number of kernels follwed by

7 x 4 with values of 3470 and 2576, respectively. Hybrids 5 x 3 and

3 x 1 produced the fewest number of kernels with values of 904 and 963,

respectively, It was observed that the later maturing hybrids produced

larger kernels and lower threshing percentage.

The threshing percentage of the hybrids ranged from 44.8 to 82.7%

in 1975 and from 39.1 to 65.7% in 1976. The average of the two years

resulted in a range of from 46.5 to 68.2% threshing for hybrids 4 x 1

and 7 x 4, respectively.

In the data from 1975 and from the two-year average, the hybrid

with the highest percentage protein was 5 x 3 and the hybrid with the

lowest percentage protein was 4 x 2. It should be noted that 5 x 3 was

a cross between two parents containing low protein percentage but this

combination of parents produced a very low grain yield. It was observed

that these lowest and highest protein percentage hybrids were
significantly (P <.01) different from most of the hybrids.

Protein yield is a function of grain yield and percentage protein.
With an increase in grain yield, it is likely that the protein yield
will increased when protein percentage remains relatively constant.
Protein yields in 1975 were generally higher due to higher grain yields
in 1975 than in 1976. The average protein yield of the two-year data
ranged from 3.6 to 9.3 grams per plant. The highest protein yield from
hybrid 7 x 6 followed by 7 x 1 while the lowest protein yielders were
4 x 2 and 5 x 3. It should be noted that the highest protein yielder
was found to be the lowest grain yielder and at the same time contained
the highest percentage protein. Grain yield seemed to be the dominant
factor in determining protein yield.

Agronomic Character Relationships

The coefficients of correlation of the nine agronomic variables
are presented in Tables VIII and IX. For parents and F_1 (Table VIII)
heading date was not significantly correlated with any of the other
eight variables. Plant height was positively and significantly (P <.01)
correlated with head weight of the parents and F_1, and with the grain
yield of the parents in 1976. These variables were not significantly
correlated in 1975. Also significant (P <.01) positive correlations
were observed between height and kernel number as well as height and
protein yield of parents in 1976. Head weight was found to be
positively and significantly (P <.01) correlated with grain yields of
parents and F_1 in 1976 and with F_1 in 1975, but only significantly
(P <.05) correlated with grain yields of the parents in 1975. Head

TABLE VIII

COEFFICIENTS OF CORRELATION OF AGRONOMIC
CHARACTERS OF PARENTS AND F_1
HYBIRDS BY YEARS

Character	1975		1976	
	P	F_1	P	F_1
HD by:				
HT	-0.2566	0.2049	-0.4360	-0.1696
HW	-0.1658	0.0753	-0.4144	-0.1571
GY	-0.0678	0.0098	-0.3859	0.0152
KW	-0.3630	0.1047	0.0601	0.1492
%P	-0.0349	-0.0564	0.1725	-0.1721
%T	0.0790	-0.0394	-0.2468	0.2058
KN	-0.0864	-0.0419	-0.4708	-0.1357
PY	-0.0725	0.0042	-0.4094	-0.0556
HT by:				
HW	0.3892	0.1827	0.8478**	0.3793**
GY	0.3333	0.0382	0.7956**	0.2675
KW	0.2978	0.1726	0.0267	-0.0270
%P	-0.0295	-0.1238	-0.2005	-0.1290
%T	-0.0114	-0.0065	0.2750	0.0564
KN	0.2982	0.0550	0.7844**	0.3200*
PY	0.3015	0.0287	0.7891**	0.2604
HW by:				
GY	0.5916*	0.5285**	0.9798**	0.9154**
KW	0.1030	0.2176	0.1094	0.3322**
%P	-0.5801*	-0.5234**	-0.2213	-0.3510**
%T	-0.0041	-0.2235	0.3910	0.5270**
KN	0.4666	0.3014*	0.8527**	0.7708**
PY	0.4632	0.1726	0.9741**	0.9165**
GY by:				
KW	-0.2370	0.1571	0.2070	0.4483**
%P	-0.1485	-0.3558**	-0.3107	-0.4588**
%T	0.7777**	0.8493**	0.5495*	0.7878**
KN	0.9502**	0.9495**	0.8289**	0.7656**
PY	0.9710**	0.9771**	0.9913**	0.9780**
KW by:				
%P	-0.0495	0.1020	-0.6272**	-0.3389**
%T	-0.3704	0.1261	0.5463*	0.4595**
KN	-0.3272	-0.0095	-0.2106	-0.1651
PY	-0.2256	0.2172	0.2014	0.3829**

TABLE VIII (CONTINUED)

Character	1975		1976	
	P	F$_1$	P	F$_1$
%P by:				
%T	0.2911	−0.1211	−0.6097*	−0.6077**
KN	−0.1330	−0.4844**	−0.1302	−0.2893*
PY	0.0590	−0.1726	−0.2442	−0.2985*
%T by:				
KN	0.7831**	0.7751**	0.3572	0.5688**
PY	0.8559**	0.8694**	0.5479*	0.7301**
KN by:				
PY	0.9225**	0.8972**	0.8224**	0.7810**

*,** — Significant at .05 and .01 levels of probability, respectively.

TABLE IX

COEFFICIENTS OF CORRELATION OF AGRONOMIC
CHARACTERS OF PARENTS, F_2,
AND BC IN 1976

Character	P	F_2	BC
HD by:			
HT	-0.2699	-0.1710	-0.9436
HW	-0.2232	0.0893	-0.0822
GY	-0.1674	0.0506	-0.0713
KW	0.2808	0.1541	-0.1765
%P	-0.1861	-0.0318	-0.1367
%T	0.0954	-0.0795	-0.1084
KN	-0.2564	-0.0362	0.0581
PY	-0.2306	0.0637	-0.1541
HT by:			
HW	0.5231*	0.3412**	0.4717**
GY	0.5745*	0.3540**	0.4732**
KW	0.1895	0.0686	0.1367
%P	-0.2706	-0.1620	-0.2355
%T	0.4603	0.1529	0.2212
KN	0.5275*	0.2331	0.3058
PY	0.5985*	0.3488**	0.4415**
HW by:			
GY	0.9362**	0.9500**	0.8696**
KW	0.2170	0.1730	0.2666
%P	-0.6157*	-0.4866**	-0.3889**
%T	0.4442	0.2834*	0.2016
KN	0.8087**	0.7036**	0.6261**
PY	0.9302**	0.9370**	0.8335**
GY by:			
KW	0.2494	0.1870	0.3112*
%P	-0.6358**	-0.5685**	-0.4766**
%T	0.6958**	0.5609**	0.6281**
KN	0.8711**	0.7291**	0.7542**
PY	0.9827**	0.9652**	0.9741**
KW by:			
%P	-0.3672	-0.2684	-0.1458
%T	0.3488	0.0885	0.2932*
KN	-0.1577	-0.4912**	-0.3046*
PY	0.2116	0.1439	0.3217*

TABLE IX (CONTINUED)

Character	P	F$_2$	BC
%P by:			
%T	−0.4784	−0.4453**	−0.3728**
KN	−0.4127	−0.3057*	−0.4009**
PY	−0.5450*	−0.3516**	−0.2176
%T by:			
KN	0.5778*	0.3976**	0.4865**
PY	0.7007**	0.5054**	0.5952**
KN by:			
PY	0.8803**	0.7343**	0.6917**

*, ** = Significant at .05 and .01 level of probability, respectively.

weights and grain yields of F_1 in both years were negatively and
significantly (P <.01) correlated with percentage protein. This
indicated that as grain yield increased protein percentage decreased.
and agreed with the previous findings reported in the literature (1,
42, 62). Head weight and KN, and HW and PY were positively and
significantly (P <.01) correlated in 1976, GY and KN, and GY and PY
were positively and significantly (P <.01) correlated in both 1975
and 1976. This reaffirmed the positive association of characters
related to yield, i.e., head weight, grain yield, kernel number, and
protein yield. There was positive and significant (P <.01) correlation
between grain yield and percentage threshing Kernel weight was found
to be negatively and significantly (P <.01) correlated with percentage
protein in 1976 but not in 1975. Kernel weight was positively and
significantly (P <.05) correlated with threshing percentage and protein
yield for the F_1 in 1976. Negative correlation coefficients were
found between kernel weight and kernel number but they were not statis-
tically significant. Percentage protein was negatively associated with
kernel number in the F_1. Threshing percentage was observed to be
positively and significantly (P <.01) correlated with kernel number and
protein yield for parents in 1975 and for F_1 in both years, but kernel
number was negatively correlated (P <.05) with percentage protein in
the F_1 hybrid generation. Since 1975 was perhaps a more normal
environment, correlations for that year should be given more weight.
In this light, GY was not associated with KW, nor was KW associated
with %P, If true, then there is a potential for increasing yield,
kernel weight, and percentage protein all at the same time.

In the F_2 and BC generations (Table IX), the coefficients of correlation indicated significant (P <.01) positive correlation between plant height and head weight and between height and grain yield. Both head weight and grain yields showed as before, significant (P <.01) negative correlations with percentage protein. It was also shown that head weight and grain yield were positively and significantly (P <.01) correlated with kernel number and protein yield, while kernel weight was negatively correlated (P <.05) with kernel number. Also, protein percentage was significantly (P <.01) and negatively correlated with threshing percentage in F_2 and BC, kernel number in BC and with protein yield in the F_2 generation. Percentage threshing, as in the F_1 was found to have positive significant (P <.01) correlation with kernel number and protein yield. Most of these agronomic correlations seemed to follow the same patterns reported by other investigators (44, 59). Even in these 1976 correlations grain yield was positively associated with kernel weight, and there would be no strong barrier to increasing both kernel weight and percentage protein.

The relationships between grain yield and percentage protein, between grain yield and kernel weight, and between grain yield and kernel number were evaluated by constructing graphs of the data. Each graph presents data on the hybrids involving one parent. Figure 1 shows the pattern of responses for hybrids derived from parent 1. An inverse relationship between grain yield and percentage protein was apparently demonstrated for each of the seven crosses while kernel number showed a direct relationship with grain yield. There was no consistant pattern of response between grain yield and kernel .

Figure 1. Relationships Among Grain Yield (GY), Percentage
Protein (%P), Kernel Weight (KW) and Kernel
Number (KN) of F_1 Hybrids Derived from Parent 1
(Parent 1 Contained High Protein and Very Large
Kernels); Average of Two Years.

weight nor between percentage protein and kernel weight, again indicating no barrier for simultaneous improvement.

For parent 2 hybrids (Figure 2), there was one consistent trend in the pattern of responses between grain yield and kernel number. It seemed that the graph showed a positive relationship between grain yield and percentage protein of crosses 3 x 2, 4 x 2 and 5 x 2. This indicated a possibility of producing hybrids with good yield and high protein if the degree of heterosis for grain yield was only sufficient to account for the increase in protein content. Percentage protein showed some negative relationship with kernel weight and grain yield.

For parent 3 which is high in protein, the pattern of response of its hybrids especially a cross between 5 anc 3 indicated that reduction in kernel size was associated with an increase in protein content and a decrease in grain yield (Figure 3). This may be attributed to the dilution effect of carbohydrate over that of nitrogen as pointed out by Stone and Tucker (56). However, for cross 7 x 3 a decrease in kernel size was more than compensated for by an increase in kernel number and an increase in grain yield.

In Figures 4 to 8, the graphs distinctly demonstrated that generally protein percentage was inversely related to grain yield while kernel number was directly related to grain yield. A decrease in kernel size resulted in a reduction of grain yield for some hybrids which likewise resulted in an increase in protein content. This increase in protein percentage which accompanied the reduction in kernel size may be attributed to the dilution effect of carbohydrate over that of nitrogen as pointed out by Stone and Tucker (56). The negative relationship between grain yield and percentage protein and
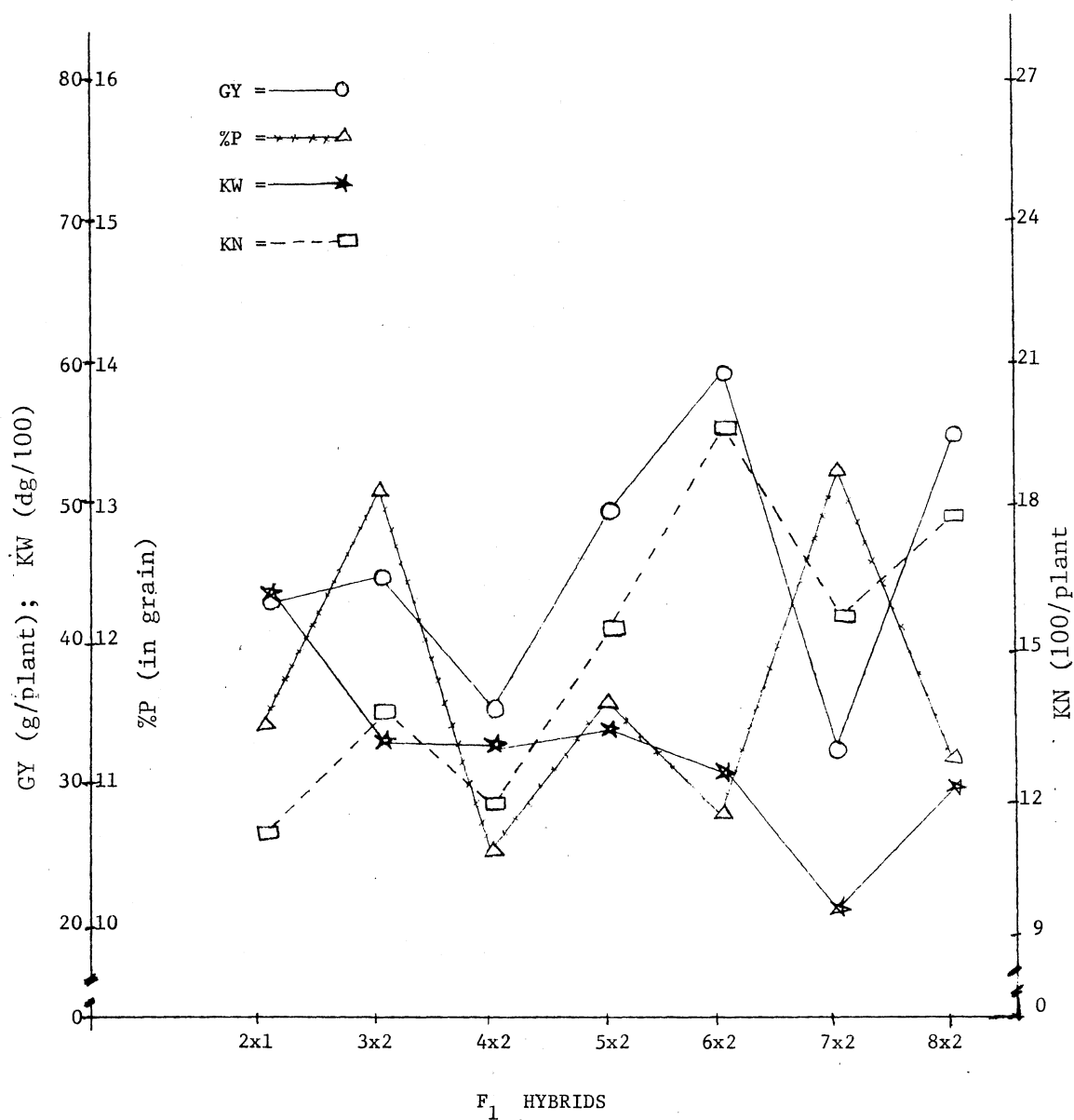
Figure 2. Relationships Among Grain Yield (GY), Percentage
           Protein (%P), Kernel Weight (KW) and Kernel
           Number (KN) of F_1 Hybrids Derived from Parent 2
           (Parent 2 Contained Low Protein and Very Large
           Kernels); Average of Two Years.
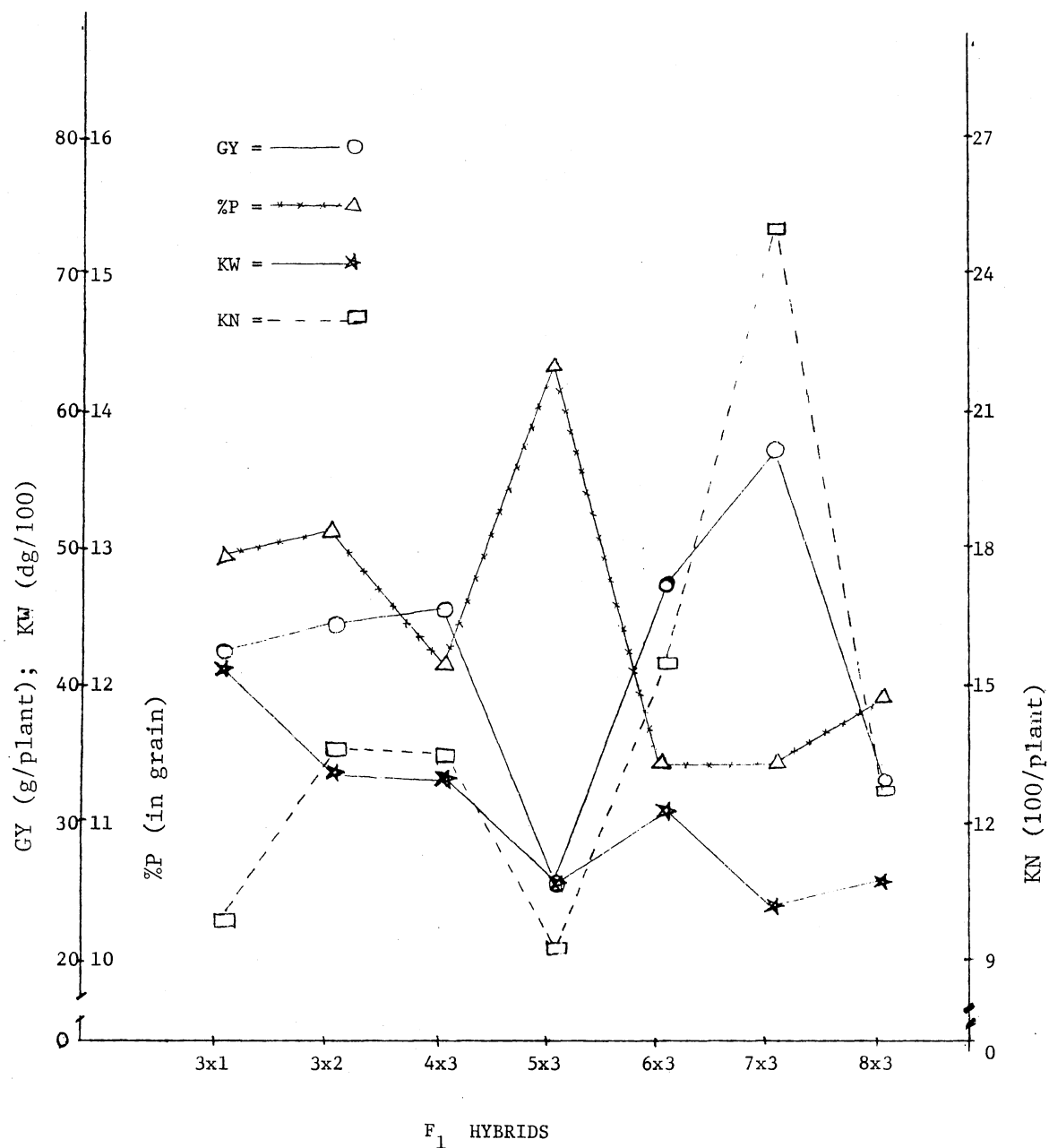
Figure 3. Relationships Among Grain Yield (GY), Percentage Protein (%P), Kernel Weight (KW) and Kernel Number (KN) of F_1 Hybrids Derived from Parent 3 (Parent 3 Contained High Protein and Large Kernels); Average of Two Years.
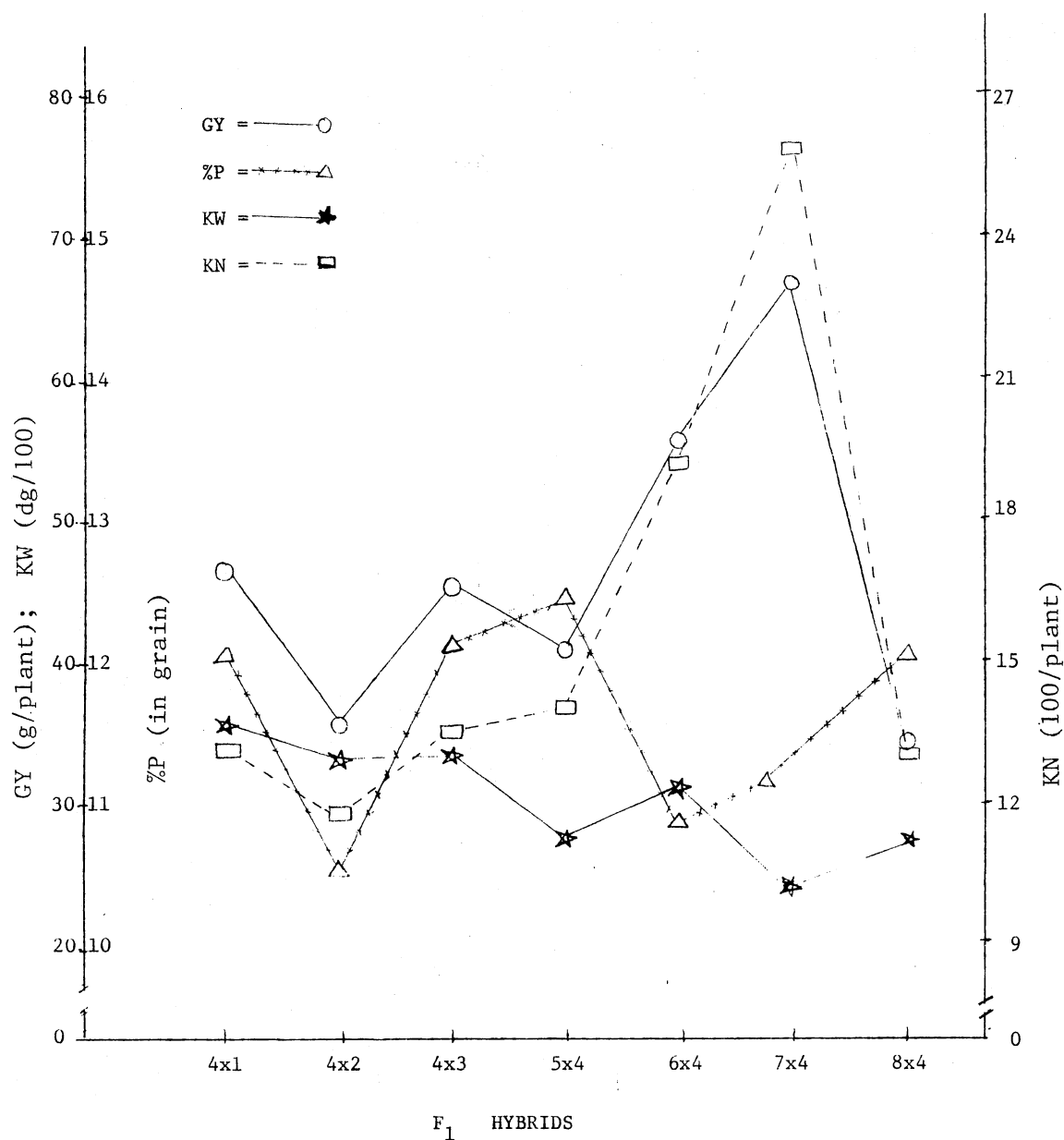
Figure 4. Relationships Among Grain Yield (GY), Percentage
Protein (%P), Kernel Weight (KW) and Kernel
Number (KN) of F_1 Hybrids Derived from Parent 4
(Parent 4 Contained Low Protein and Large
Kernels); Average of Two Years.
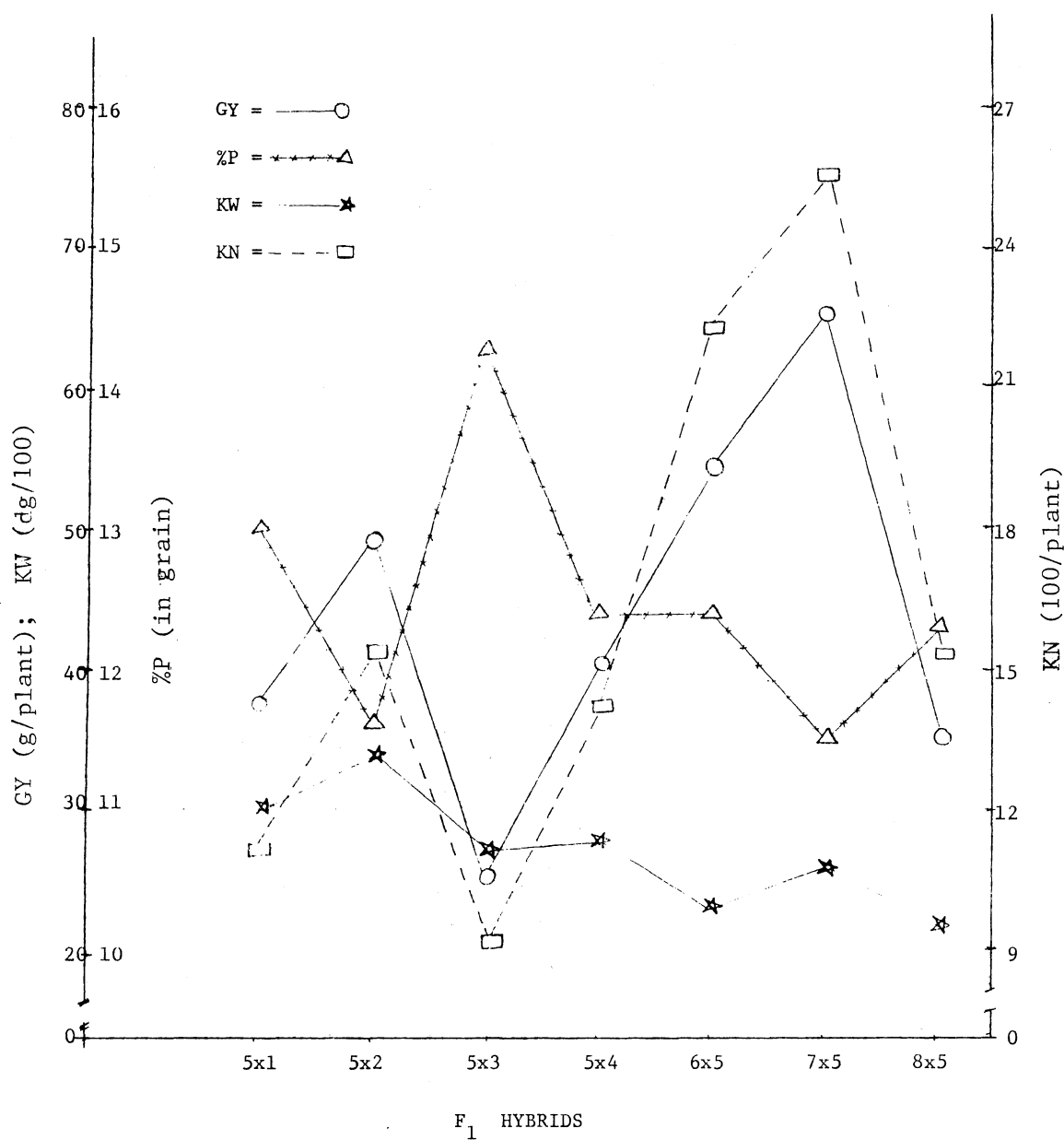
Figure 5. Relationships Among Grain Yield (GY), Percentage
Protein (%P), Kernel Weight (KW) and Kernel
Number (KN) of F_1 Hybrids Derived from Parent 5
(Parent 5 Contained High Protein and Medium-
sized Kernels); Average of Two Years.
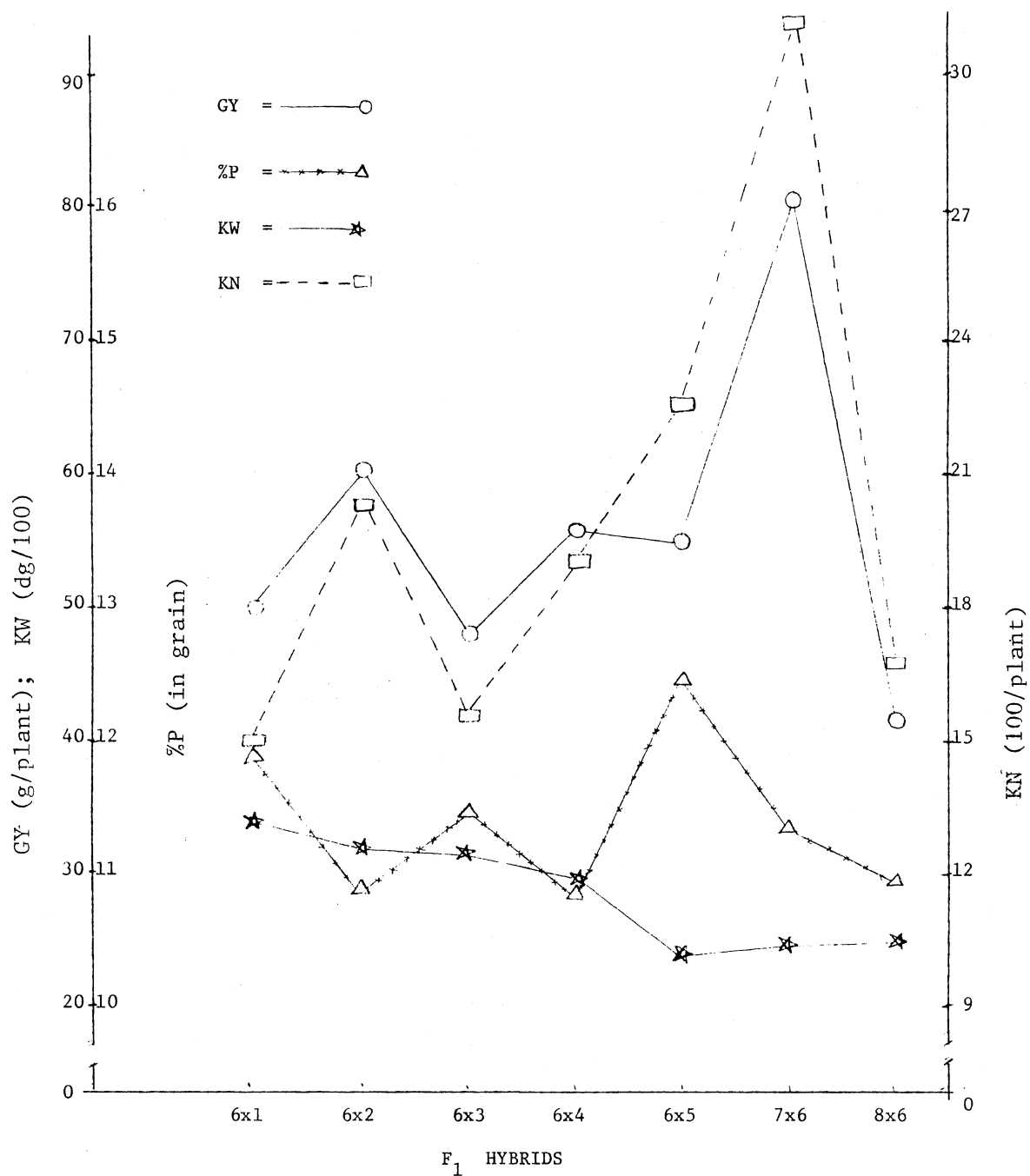
Figure 6. Relationships Among Grain Yield (GY), Percentage
Protein (%P), Kernel Weight (KW) and Kernel
Number (KN) of F_1 Hybrids Derived from Parent 6
(Parent 6 Contained Low Protein and Medium-sized
Kernels); Average of Two Years.
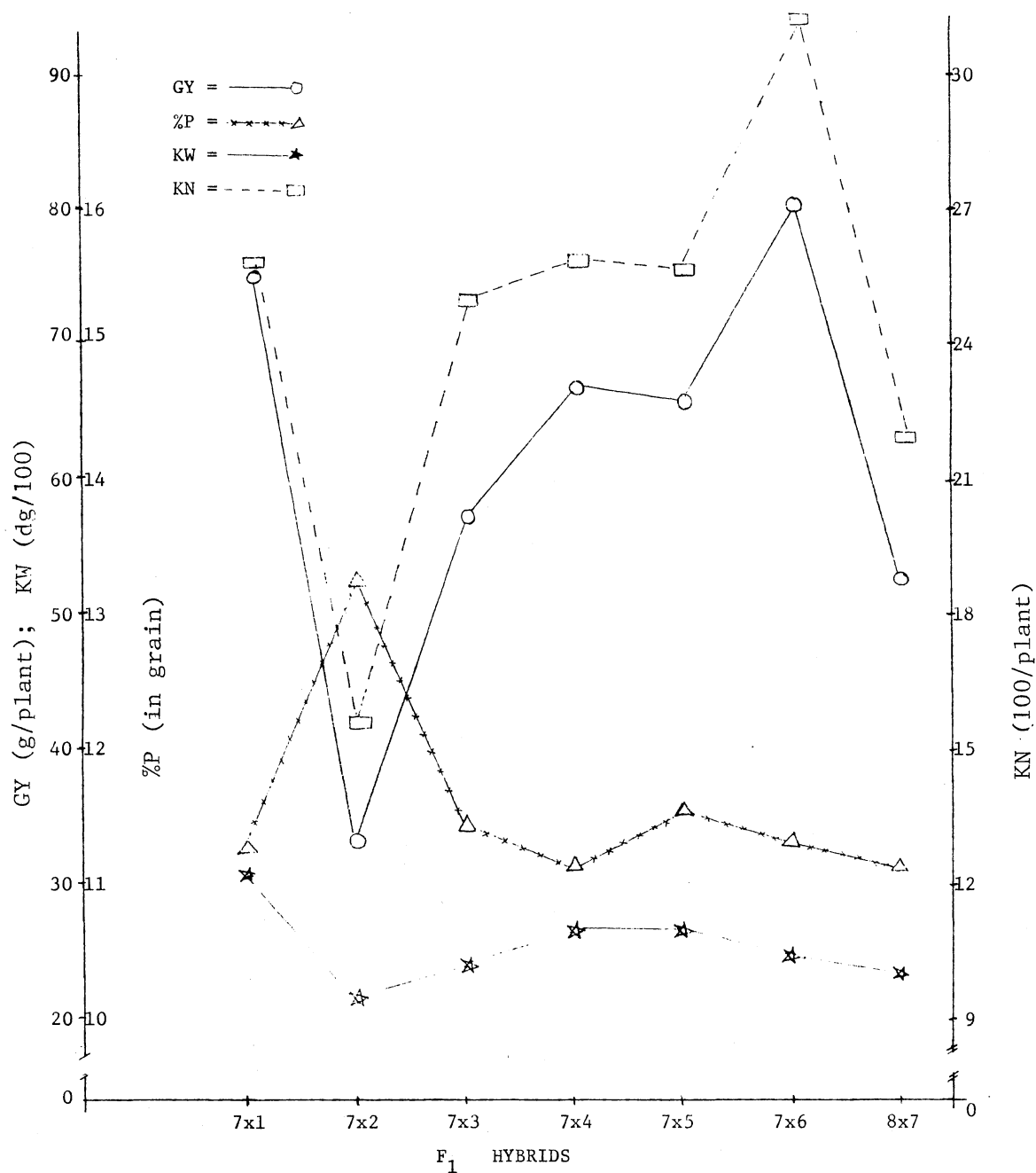
Figure 7. Relationships Among Grain Yield (GY), Percentage
Protein (%P), Kernel Weight (KW) and Kernel Number
(KN) of F_1 Hybrids Derived from Parent 7
(Parent 7 Contained High Protein and Small-sized
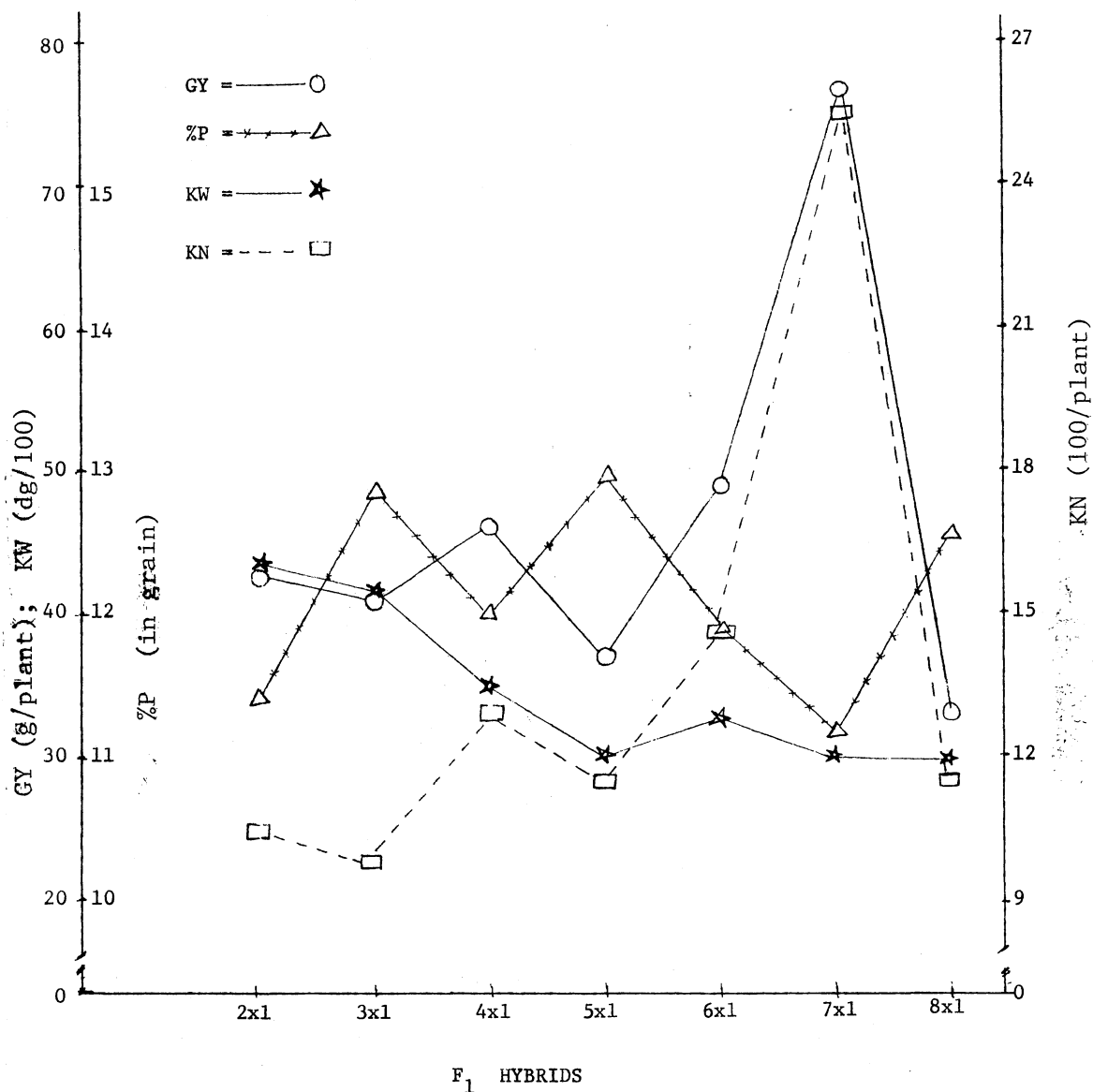Kernels); Average of Two Years.
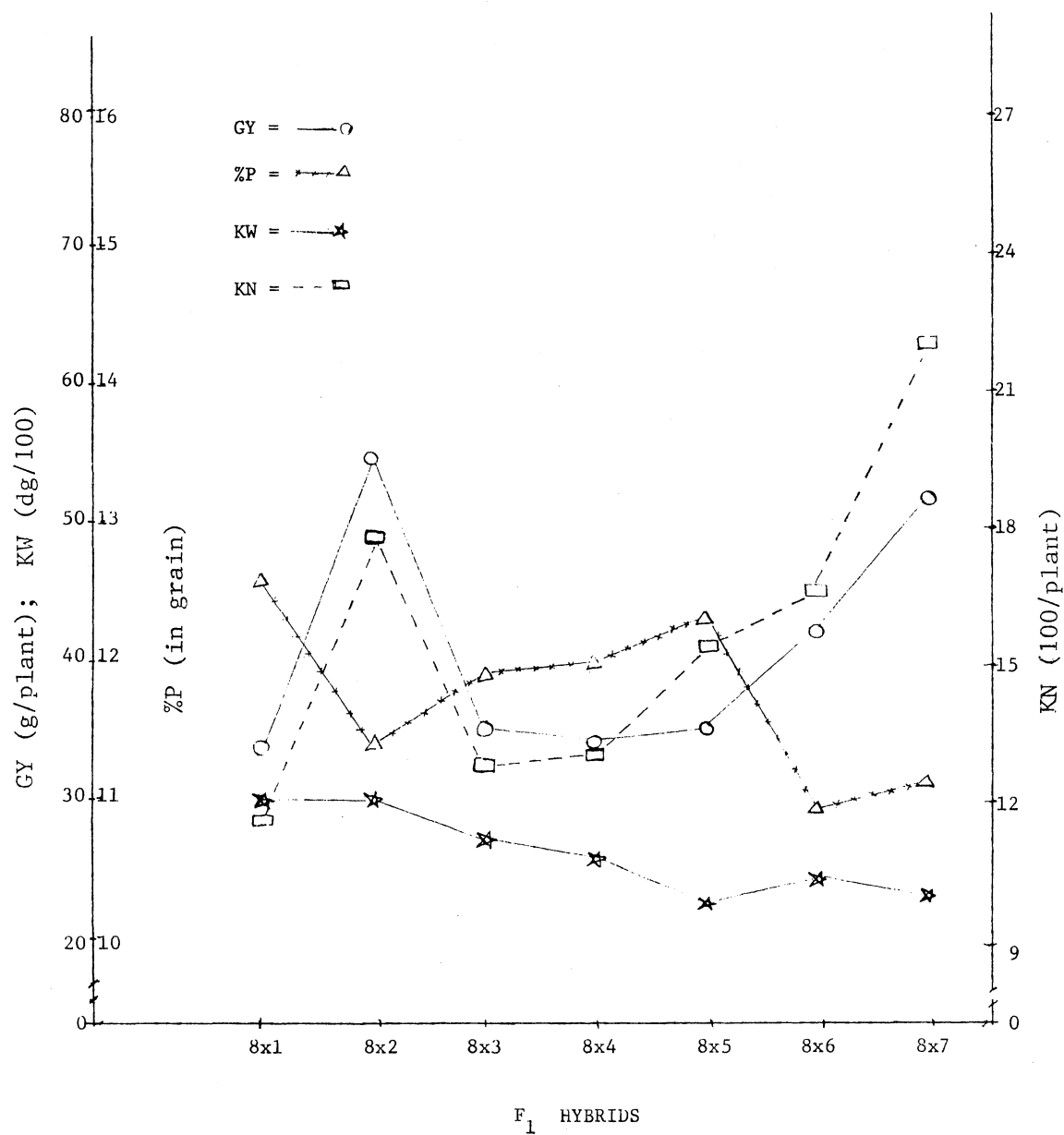
Figure 8. Relationships Among Grain Yield (GY), Percentage
Protein (%P), Kernel Weight (KW) and Kernel
Number (KN) of F_1 Hybrids Derived from Parent 8
(Parent 8 Contained Low Protein and Small-sized
Kernels); Average of Two Years.

the positive relationship between grain yield and kernel number also confirmed previous findings reported in the literature (1, 40, 63). The graphs generally demonstrated the decline in kernel size when large kerneled parents were crossed to large, medium, and small-kerneled parents.

Estimates of Percent Heterosis

The increase in grain yield, kernel weight and percentage protein due to heterotic effects of F_1 hybrids derived from eight parents were calculated as mean deviations of the F_1 hybrids from the midparents and high parents. Analyses of variance of these variables attributed to heterosis are presented in Table X. The mean square table showed that there was no hybrid x year interaction for percent heterosis of percentage protein as mean deviation from the midparents. However, all other variables showed significant (P < .01) hybrid x year interactions regardless of whether the heterotic effect was from midparent or high parent deviations. These results suggested the influence of environment on heterosis with respect to grain yield, kernel weight and percentage protein.

Tables XI and XII show the estimates of percent heterosis of the 28 hybrids by years and their averages, respectively. For grain yield in 1975 (Table XI), cross 5 x 2 gave the highest percent heterosis from midparent, followed very closely by crosses 7 x 5 and 3 x 1, respectively. In 1976 cross 7 x 1 and cross 7 x 6 gave the highest percent heterosis for grain yield from the midparent deviation, and also from the high parent deviation. For the two-year average (Table XII), hybrid 7 x 1 was the highest in percent heterosis followed by

TABLE X

THE ANALYSES OF VARIANCE OF PERCENTAGE HETEROSIS OF
GRAIN YIELD (GY), KERNEL WEIGHT (KW) AND
PERCENTAGE PROTEIN (%P) FOR
28 F_1 HYBRIDS

Source	df	GY		KW		%P	
		MP	HP	MP	HP	MP	HP
Year	1	60831.82	40360.56	9982.27	1179.74	0.55	26.14
Rep x year	6	9166.26	8463.15	1644.73	1007.85	195.06	161.57
Hybrids	27	24575.16**	18893.63**	1009.96**	1557.61**	335.05**	322.63**
Hybrid x year	27	9597.58**	8599.36**	917.75**	908.16**	88.80	117.05**
Error	162	4151.44	3563.81	282.57	228.57	228.21	63.58

*,** = Significant at .05 and .01 levels of probability, respectively.

TABLE XI

ESTIMATES OF PERCENT HETEROSIS OF GRAIN YIELD (GY), KERNEL WEIGHT (KW), AND PERCENTAGE PROTEIN (%P) AS DEVIATIONS FROM MIDPARENTS AND HIGH PARENTS

F1 Hybrids	1975 GY MP	1975 GY HP	1975 KW MP	1975 KW HP	1975 %P MP	1975 %P HP	1976 GY MP	1976 GY HP	1976 KW MP	1976 KW HP	1976 %P MP	1976 %P HP
2 x 1	179.00	123.69	18.93	15.13	-14.17	-21.18	199.53	168.59	-21.76	-31.59	-18.48	-21.66
3 x 1	212.43	149.97	17.67	0.93	- 9.24	-12.66	50.43	22.00	- 7.72	-19.80	- 1.12	- 7.59
4 x 1	117.12	70.23	8.00	- 7.96	- 1.10	-11.75	43.04	8.27	-23.11	-35.07	- 8.07	-20.90
5 x 1	175.64	145.25	- 4.18	-26.05	- 8.78	-10.74	9.11	-11.92	-23.34	-39.93	- 5.39	-11.81
6 x 1	91.75	32.12	19.35	- 6.43	- 0.47	-13.95	37.65	5.03	-32.14	-50.67	- 9.57	-20.69
7 x 1	195.94	122.37	- 3.72	-31.92	-16.24	-19.84	253.84	200.37	- 9.56	-37.92	-20.02	-24.59
8 x 1	92.64	74.17	4.70	-18.00	- 2.44	-10.51	113.11	88.53	-24.64	-48.87	- 8.25	-14.23
3 x 2	67.57	36.34	2.88	-11.89	2.22	- 3.27	138.31	96.96	-25.71	-36.47	- 0.48	- 4.97
4 x 2	159.80	130.02	7.21	- 8.70	-12.80	-15.82	43.26	14.29	-23.57	-32.40	-10.70	-21.81
5 x 2	215.70	150.37	15.01	-11.34	-19.10	-27.06	109.94	51.63	- 8.18	-17.95	- 6.67	-11.93
6 x 2	78.29	46.74	10.56	-13.44	- 6.19	-11.97	104.98	50.28	-20.83	-35.52	-10.05	-19.44
7 x 2	31.04	13.60	-22.74	-45.17	- 0.60	- 4.92	-12.00	-35.45	-25.16	-43.84	2.96	- 1.24
8 x 2	158.49	110.05	7.09	-16.33	- 7.78	-11.36	169.32	144.26	-15.07	-37.69	-14.15	-18.49
4 x 3	66.50	39.32	11.25	7.52	- 2.51	-10.39	24.97	- 9.63	- 6.57	-16.29	6.33	- 2.73
5 x 3	26.37	- 2.22	- 4.70	-15.90	6.46	1.13	-17.44	-33.04	- 4.40	-16.69	9.00	7.07
6 x 3	84.31	45.00	19.02	7.03	- 4.95	-15.44	78.79	41.37	0.39	-20.72	- 1.41	- 7.99
7 x 3	105.15	82.70	- 0.87	-21.45	-16.92	-18.86	95.91	51.83	-22.22	-39.69	- 7.26	-11.04
8 x 3	83.82	51.38	10.62	- 0.34	- 5.68	-11.05	31.83	8.29	-17.05	-39.47	- 5.09	- 8.38

TABLE XI (CONTINUED)

F_1 Hybrids	1975						1976					
	GY		KW		%P		GY		KW		%P	
	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
5 x 4	71.13	33.79	- 3.45	-14.39	4.04	- 8.83	12.94	-15.71	12.24	3.64	- 0.72	- 8.56
6 x 4	41.80	21.86	7.95	- 2.58	- 3.21	- 6.56	50.14	20.25	10.12	- 7.32	5.32	2.94
7 x 4	105.77	78.69	6.93	-14.83	- 5.89	-12.63	92.32	57.23	6.10	-15.33	- 6.80	-15.88
8 x 4	41.10	27.74	6.79	- 3.68	5.68	2.01	24.53	- 7.19	- 8.63	-29.57	2.83	- 5.88
6 x 5	92.67	36.73	4.68	2.53	- 2.40	-17.06	32.38	20.39	-11.55	-21.32	6.89	0.66
7 x 5	215.00	138.22	27.64	12.54	-15.44	-20.64	154.66	126.31	19.11	1.64	-11.45	-14.28
8 x 5	121.16	98.53	3.45	1.23	- 7.12	-16.25	0.03	-28.05	- 7.22	-25.20	3.07	- 6.99
7 x 6	82.54	58.21	- 1.54	-14.76	1.27	- 9.21	229.42	202.50	49.76	29.22	- 9.17	-16.17
8 x 6	42.56	3.94	7.42	5.19	2.02	- 4.36	44.14	2.08	12.23	- 3.72	-10.34	-16.10
8 x 7	137.39	94.30	6.60	- 7.15	- 9.95	-13.85	53.68	11.93	37.16	32.71	-13.62	-15.95
Mean	110.42	71.54	6.52	- 8.58	- 5.40	-12.04	77.46	44.70	- 6.83	-22.71	- 5.30	-11.38
LSD												
.05	77.71	70.06	10.76	10.54	9.24	8.23	99.54	93.71	31.14	27.68	12.58	13.28
.01	102.13	92.07	14.14	13.86	12.15	10.82	130.82	123.16	40.93	36.36	16.54	17.46

TABLE XII

ESTIMATES OF PERCENT HETEROSIS OF GRAIN YIELD (GY),
KERNEL WEIGHT (KW), AND PERCENTAGE PROTEIN
(%P) AS DEVIATIONS FROM MIDPARENTS
AND HIGH PARENTS (AVERAGE
OF TWO YEARS)

F_1 Hybrids	GY		KW		%P	
	MP	HP	MP	HP	MP	HP
2 x 1	188.76	146.14	- 1.42	- 8.23	-16.33	-21.42
3 x 1	131.43	85.99	4.98	- 9.44	- 5.18	-10.12
4 x 1	80.08	39.25	- 7.57	-21.52	- 4.58	-16.33
5 x 1	92.38	66.67	-13.76	-32.99	- 7.08	-11.27
6 x 1	64.70	18.57	- 6.40	-28.55	- 5.02	-17.32
7 x 1	224.89	161.37	- 6.64	-34.92	-18.13	-22.22
8 x 1	102.88	81.35	- 9.97	-33.44	- 5.35	-12.37
3 x 2	102.94	66.65	-11.42	-24.18	0.87	- 4.12
4 x 2	101.53	72.16	- 8.18	-20.55	-11.75	-18.82
5 x 2	162.82	101.00	3.42	-14.65	-12.89	-19.50
6 x 2	91.63	48.51	- 5.14	-24.50	- 8.12	-15.71
7 x 2	9.52	-10.92	-23.95	-44.50	1.18	- 3.08
8 x 2	163.90	127.16	- 3.99	-27.01	-10.97	-14.93
4 x 3	54.74	14.84	2.34	- 4.39	1.91	- 6.56
5 x 3	4.47	-17.63	- 4.55	-16.29	7.73	4.10
6 x 3	81.55	43.18	9.70	- 6.85	- 3.18	-11.72
7 x 3	100.53	67.27	-11.55	-30.54	-12.09	-14.95
8 x 3	57.83	29.83	- 3.22	-19.91	- 5.38	- 9.71
5 x 4	42.03	9.04	4.39	- 5.38	1.66	- 8.69
6 x 4	45.97	21.05	9.03	- 4.95	1.06	- 1.81
7 x 4	99.05	67.96	6.51	-15.08	- 6.34	-14.25
8 x 4	32.82	10.27	- 0.92	-16.64	4.24	- 1.94
6 x 5	62.53	28.57	- 3.44	- 9.39	2.25	- 8.20
7 x 5	184.83	132.27	23.38	7.09	-13.44	-17.46
8 x 5	60.59	30.24	- 1.89	-11.98	- 5.09	-11.62
7 x 6	155.98	130.36	24.11	7.23	- 3.95	-12.69
8 x 6	43.35	3.01	9.83	0.73	- 4.16	-10.22
8 x 7	95.53	53.11	21.88	12.78	-11.79	-14.89
Mean	93.94	58.12	- 0.16	-15.64	- 5.35	-11.71
LSD						
.05	63.14	58.50	16.47	14.80	7.81	7.81
.01	82.98	76.89	21.65	19.46	10.26	10.27

2 x 1 and 7 x 5. It was observed that the ranges in heterosis for grain yield from high parent deviation were from -2.22% to as high as 150.37% in 1975, and from -35.45 to 202.50% in 1976. The mean of all estimates was higher in 1975 than in 1976. For the average of the two years, the percentage heterosis of grain yield ranged from 4.47 to 224.89% for the midparent deviation and from -17.63 to 161.37% from the high parent deviation.

Percentage heterosis for kernel weight was mostly negative for both years. However, in the midparent deviation, there were more cases of positive heterosis in 1975 than in 1976 probably because of the differential effect of greenbug and drought in 1976 planting. In 1975, hybrid 7 x 5 a cross of a small x a medium-sized kernel gave the highest percentage heterosis followed by hybrids 6 x 1, 6 x 3, and 2 x 1 for the midparent deviation, but 2 x 1 was the highest for the high parent deviation. The latter crosses involved large kerneled parents. In 1976, and in the average of the two years, hybrid 7 x 6 gave the highest percentage heterosis for kernel weight from midparent. It was observed that this hybrid also was the highest grain yielder which seemed to suggest that percent heterosis in kernel weight could serve as a determining factor for grain yield. In 1975 and in both years, the highest negative heterosis was hybrid 7 x 2. However, it was observed that this hybrid was not the lowest grain yielder.

As with kernel weight, the percent heterosis attributed to percentage protein in the grains gave mostly negative figures for the two years of data. Only one hybrid (5 x 3) consistently gave positive heterosis for percentage protein. It should be noted that this hybrid was a cross of parents each containing high protein percentage. The

mostly negative heterosis of percentage protein for the hybrid was in agreement with what has been reported by Wilson (63) concerning this trait. This also seemed to indicate low protein was dominant over high protein which seemed to confirm previous findings reported in the literature (18, 22). It was observed that out of 28 crosses, only eight crosses gave positive percent heterosis as mean deviation from midparent and only one cross from the high parent deviation for the two-year average.

<div align="center">Combining Ability Analyses of Diallel Cross</div>

The combining ability analyses of the diallel of F_1 hybrids and their parents was computed. The estimates of mean squares and variance components for general combining ability (g.c.a.) and for specific combining ability (s.c.a.) together with their interactions with years are presented in Table XIII. All five traits (GY, KW, KN, %P, and PY) revealed significant (P <.01) levels of general and specific combining ability effects. The significant (P <.01) g.c.a. x year interactions for KW and %P as well as the significant (P <.01) s.c.a. x year inter-actions for KW indicated that these traits are influenced by the environment and, therefore, must be evaluated each year seperately. Grain yield, KN, and PY revealed significant (P <.05) s.c.a. x year interactions while g.c.a. x year interactions on these traits were not significant indicating that the additive gene action governing these traits were not affected by the environment while the nonadditive gene actions were affected.

The magnitude of variance components for GY, KN, %P, and PY indicated the importance of specific combining ability on these traits.

TABLE XIII

ANALYSES OF VARIANCE FOR COMBINING ABILITY ADAPTED
FROM GRIFFING.'S METHOD I AND MODEL II SHOWING
MEAN SQUARES AND COMPONENTS OF VARIANCES
ASSOCIATED WITH GRAIN YIELD (GY),
KERNEL WEIGHT (KW), KERNEL
NUMBER (KN), PERCENTAGE
PROTEIN (%P) AND
PROTEIN YIELD
(PY)(PARENTS
AND F_1, 1975
-1976)

Source	df	GY	KW	KN	%P	PY
			(Mean Squares)			
g.c.a.[1]	7	3155.50**	14.36**	4547273.50**	21.30**	31.56**
s.c.a.[2]	28	1550.49**	0.34**	1550961.90**	4.93**	17.19**
g.c.a. x year	7	343.81	3.38**	326289.42	4.99**	2.69
s.c.a. x year	28	339.12*	0.51**	335964.96*	1.05	4.49*
Error	216	207.77	0.15	200345.46	0.79	2.40
			(Components of Variances)			
$\hat{o}^2$g.c.a.	--	35.14	0.14	52762.30	0.20	0.36
$\hat{o}^2$s.c.a.	--	151.42	-0.02	151874.62	0.49	1.59
$\hat{o}^2$g.c.a. x year	--	3.40	0.08	3148.60	0.11	0.01
$\hat{o}^2$s.c.a. x year	--	32.84	0.09	33904.88	0.07	0.52
g.c.a./s.c.a.	--	0.21	-7.00		0.35	0.41	0.23

[1] = General Combining Ability
[2] = Specific Combining Ability
*,** = Significant at .05 and .01 level of probability, respectively.

This suggested that nonadditive genetic action influenced these traits much more than the additive genetic effect. Kernel weight seemed to be much more governed by additive gene action than the nonadditive gene action. Except for %P and KW the s.c.a. x year components were considerably greater than the g.c.a. x year term. With respect to the ratio of additive genetic variance over that of nonadditive variance (g.c.a./s.c.a.), only kernel weight showed a higher additive genetic variance suggesting that this trait was governed by additive gene action. This reaffirmed the findings of Voigt, et al. (59). The ratio of g.c.a. to that of s.c.a. for GY, KN, %P, and PY indicated values less than 50% which implied the importance of dominant gene actions on these traits assuming there were no interallelic gene effects. These results were in agreement with the findings reported by Wilson (63) in his study of protein content in grain sorghum.

The estimates of the general combining ability effects of eight parents on their hybrids in the diallel crosses in 1975 and 1976 are presented in Table XIV. Parent 7 gave the highest combining ability effects for GY among the parents for both years followed by parent 6. Parent 8 was the lowest in general combining ability effect in the two-year average with the highest negative value among the eight parents.

For the weight of 100 kernels (KW), parent 1 gave the highest general combining ability effects followed by parent 2 in the two-year average. For protein percentage (%P), parent 5 produced the highest value followed by parent 1 in 1975 and both years but parent 1 and 3 produced the highest percentage protein in 1976.

The number of kernels (KN) and protein yield (PY) followed the same pattern as grain yield (GY) since these two variables are generally

TABLE XIV

ESTIMATES OF GENERAL COMBINING ABILITY EFFECTS
FOR GRAIN YIELD (GY), KERNEL WEIGHT (KW),
PERCENTAGE PROTEIN (%P), KERNEL NUMBER
(KN), AND PROTEIN YIELD (PY) FOR
DIALLEL CROSS (PARENTS AND
F_1 OF 1975 AND 1976)

Variable	Parent								SE($\hat{g}i$)
	1	2	3	4	5	6	7	8	
1975									
GY	− 3.14	− 0.20	− 4.45	− 1.96	− 6.55*	9.68*	10.50*	− 3.88	2.58
KW	0.87*	0.80*	0.10*	0.03	− 0.42*	− 0.23*	− 0.84*	− 0.31*	0.04
%P	0.59*	− 0.58*	0.46*	− 0.39*	1.02*	− 0.77*	− 0.15	− 0.18	0.10
KN	−386.68*	−307.16*	−220.23*	−117.77	−100.81	385.78*	788.12*	− 41.07	69.18
PY	− 0.08	− 0.27	0.29	− 0.35	− 0.39	0.75*	1.14*	0.51*	0.28
1976									
GY	− 2.62	− 4.39*	− 4.16*	3.09*	0.61	6.46*	11.59*	− 9.36*	1.56
KW	0.53*	0.06	0.23*	0.15*	− 0.05	− 0.21*	− 0.25*	− 0.46*	0.07
%P	0.49*	0.45*	0.49*	− 0.75*	0.29	− 0.71*	− 0.11	− 0.15	0.16
KN	−307.49*	−174.07*	288.86*	21.71	− 26.37	372.24*	638.99*	−236.15*	63.08
PY	− 0.21*	− 0.43*	− 0.34*	0.19	0.05	0.58*	1.27*	− 1.11*	0.17
Both Years									
GY	− 2.88	− 2.30	− 4.31*	0.56	− 3.58*	8.07*	11.04*	− 6.60*	1.56
KW	0.70*	0.43*	0.16	0.09*	− 0.23*	− 0.22*	− 0.54*	− 0.39*	0.05
%P	0.54*	0.06	0.48*	− 0.57*	0.65*	− 0.74*	− 0.13	− 0.17	0.09
KN	−347.18*	−240.61*	−254.54*	− 48.03	− 63.59	379.01*	713.56*	−138.62*	48.60
PY	− 0.15	− 0.35	− 0.31	− 0.08	− 0.17	0.66*	1.21*	− 0.81*	0.17

*Significant from zero at .05 level of probability.

related to GY. As in GY, parent 7 gave the highest values for these two variables followed by parent 6. These two variables like GY, were found to be less affected by the environment.

The importance of general combining ability analysis in plant breeding lies in its usefulness in discriminating the performance of the lines with respect to a variety of crosses where each was involved. So that, lines which gave high values in general combining ability when selected, generally performed well in a wide variety of crosses. The result of this investigation indicated parent 7 as the best line for grain yield, kernel number, and protein yield, parent 1 for kernel weight, and parent 5 for percentage protein.

Table XV shows the estimates of specific combining ability effects for GY, KW, and KN. The range in specific combining ability effects for GY was from -18.24 to 28.41 in 1975. Cross 8 x 2 gave the highest value followed by cross 7 x 1. In 1976, hybrid combination 7 x 6 gave the highest value followed by 7 x 1 indicating s.c.a. x year inter- action as discussed before. In the average of two years, 7 x 1 gave the highest value for specific combining ability.

The range in specific combining ability effects for KW was from -0.85 to 0.69 in 1975. Hybrid 7 x 5 gave the highest value followed by 2 x 1. In 1976, the range in specific combining ability values for KW was from -0.59 to 0.65. Hybrid 7 x 6 produced the highest effect. In the average of both years hybrid 7 x 5 gave the highest specific combining ability for KW. Ironically, this hybrid was a cross of small times medium-sized kerneled parents.

The range in specific combining ability effects for KN in 1975 was from -423.43 to 720.60. In 1976, the range was from -663.88 to

TABLE XV

ESTIMATES OF SPECIFIC COMBINING ABILITY EFFECTS
FOR GRAIN YIELD (GY), KERNEL WEIGHT (KW),
AND KERNEL NUMBER (KN) OF F_1
GENERATION FROM DIALLEL
CROSSES IN 1975
AND 1976

F_1 Hybrid	1975			1976			Average of 1975 & 1976		
	GY	KW	KN	GY	KW	KN	GY	KW	KN
2 x 1	0.12	0.62*	- 39.66	9.50*	-0.13	262.82	4.81	0.24	111.58
3 x 1	11.35	0.42*	157.64	- 1.36	0.22	-119.50	5.00	0.32*	19.07
4 x 1	11.38	0.06	224.80	- 0.67	-0.40	81.53	5.35	-0.17	153.17
5 x 1	8.28	-0.39*	320.63	- 7.24	-0.36	-244.49	0.52	-0.37*	38.07
6 x 1	8.57	0.40*	-119.32	- 7.54	-0.59*	- 93.54	0.52	-0.10	-106.43
7 x 1	24.17*	-0.25*	544.08*	26.58*	0.02	759.45*	25.37*	-0.12	651.77*
8 x 1	- 5.89	-0.10	-165.01	5.89	-0.34	382.75	- 0.01	-0.20	108.87
3 x 2	5.89	-0.11	168.20	9.60*	-0.29	432.77*	7.74	-0.20	300.48*
4 x 2	- 9.62	0.10	-229.96	- 2.97	-0.33	72.68	- 6.29	-0.12	- 78.64
5 x 2	11.39	0.34*	138.16	12.42*	0.10	457.76*	11.90*	0.27	297.96*
6 x 2	15.86*	0.14	162.20	4.79	-0.24	364.93	10.33*	-0.05	263.57
7 x 2	-16.33*	-0.85*	-293.23	-22.84*	-0.51*	-663.88*	-19.59*	-0.68*	-478.56*
8 x 2	28.41*	0.07	629.01*	12.48*	-0.02	539.36*	20.44*	0.04	584.28*
4 x 3	9.32	0.17	196.27	1.61	0.02	- 16.38	5.47	0.10	89.94
5 x 3	11.03	-0.31*	-203.71	- 9.56*	0.02	-444.52*	-10.29*	-0.15	-324.12*
6 x 3	- 7.26	0.31*	-443.43*	6.94	0.12	147.00	- 0.16	0.21	-138.21
7 x 3	12.19	-0.09	474.56*	1.55	-0.47*	474.82*	6.87	-0.28*	474.69*
8 x 3	-17.14	0.13	106.25	1.06	-0.20	117.37	2.99	-0.02	111.81

TABLE XV (CONTINUED)

F_1 Hybrid	1975			1976			Average of 1975 & 1976		
	GY	KW	KN	GY	KW	KN	GY	KW	KN
5 x 4	1.10	-0.23*	162.78	- 1.25	-0.34	-240.79	- 0.07	0.06	- 39.00
6 x 4	3.13	0.01	45.70	3.41	0.25	- 23.44	3.27	0.13	11.13
7 x 4	16.07*	0.18	386.42	6.95	0.04	341.51	11.51*	0.11	363.96*
8 x 4	-18.24*	0.05	-145.83	- 1.94	-0.14	145.33	- 3.14	-0.05	- 50.24*
6 x 5	14.84	-0.06	595.59*	- 1.99	-0.27	154.32	6.42	-0.16	374.96*
7 x 5	9.64	0.69*	- 24.53	20.21*	0.25	769.02*	14.93*	0.47*	372.25*
8 x 5	-14.42	0.01	330.50	- 3.31	-0.12	22.90	2.17	-0.08	176.70
7 x 6	8.47	-0.13	720.60*	33.27*	0.65*	941.40*	20.87*	0.26	831.00*
8 x 6	3.96	-0.15	- 87.20	- 3.26	0.18	-192.05	- 3.61	0.07	-139.64
8 x 7	15.22*	-0.15	590.12*	- 6.58	0.02	-470.66*	4.34	0.30*	59.73
SE($\hat{s}_{ij}$)	7.92	0.11	212.06	4.77	0.22	193.67	4.79	0.14	148.97

*Significant from zero at .05 level of probability.

941.40. Hybrid 7 x 6 gave consistently the highest positive values in 1975, 1976 and in the average of two years. However, many of the hybrids did not give consistent specific combining ability effects for the two years of data.

The average of the two years of data for the three variables indicated three hybrids with high positive values for GY and KW. For GY these crosses were 7 x 1, 7 x 6, and 8 x 2, and for KW these were 7 x 5, 3 x 1, and 8 x 7. For KN, the three crosses which gave high positive values were 7 x 6, 7 x 1, and 8 x 2. It will be recalled that cross 7 x 6 was the highest grain yielder followed by 7 x 1 (Table VII). This indicated that specific combining ability effects for GY and KN determine the performance of these traits. On the other hand, specific combining ability for KW was not reflected in the GY in the two-year average but was reflected in 1976. This means that crosses with high specific combining ability produced correspondingly high GY in 1976 but not in the average of two years.

For percentage protein (%P)(Table XVI), crosses 5 x 3 and 7 x 2 gave the highest specific combining ability effects in 1975, and 7 x 2 gave the highest in 1976 and in the two-year average since the same hybrids were high in percentage protein in the previously shown data. This indicated the importance of specific combining ability effects governing this character.

In the same table (Table XVI) the data showed that in 1975 hybrid 7 x 1 gave the highest specific combining ability effects for PY. In 1976, hybrid 7 x 6 was the highest in PY followed by 7 x 1. In the two-year average, 7 x 1 gave the highest specific combining ability effect followed by 7 x 6. The same hybrids showed high protein yield

TABLE XVI

ESTIMATES OF SPECIFIC COMBINING ABILITY EFFECTS
OF PERCENTAGE PROTEIN (%P) AND PROTEIN
YIELD (PY) BY YEARS

F_1 Hybrids	1975		1976		Average of 1975 & 1976	
	%P	PY	%P	PY	%P	PY
2 x 1	-0.83	-0.28	-1.42*	0.84	-1.12*	0.28
3 x 1	-0.60	1.33	0.39	0.01 \	-0.10	0.67
4 x 1	0.33	1.69*	-0.32	-0.08	0.01	0.81
5 x 1	-0.42	1.09	-0.03	-0.79	-0.22	0.15
6 x 1	0.35	1.34	-0.33	-0.85	0.01	0.24
7 x 1	-1.07*	2.28*	-1.40*	2.64*	-1.23*	2.46*
8 x 1	-0.28	-0.52	0.09	0.81	0.15	0.13
3 x 2	0.93*	1.25	0.29	1.29*	0.61*	1.27*
4 x 2.	-0.99*	-1.59	-0.85	-0.46	-0.92*	1.02*
5 x 2	-1.65*	0.63	-0.42	1.51*	-1.04*	1.07*
6 x 2	-0.22	1.41	-0.61	0.45	-0.41	0.93
7 x 2	1.05	-1.27	1.66*	-2.40*	1.36*	-1.83*
8 x 2	-0.31	-2.95*	-0.91	1.29*	-0.62*	0.06
4 x 3	-0.17	0.98	0.45	0.30	0.14	0.64
5 x 3	1.42*	-0.84	0.85	-1.05*	1.14*	-0.94
6 x 3	-0.47	-1.03	-0.22	-0.71	-0.34	-0.16
7 x 3	-1.40*	0.67	-0.52	0.17	-0.96*	0.42
8 x 3	-0.41	0.44	0.40	0.01	0.43	0.22
5 x 4	0.84*	0.64	-0.20	-0.17	0.32	0.23
6 x 4	-0.43	-0.03	0.67	0.58	0.12	0.28
7 x 4	-1.12*	1.68*	-0.26	0.71	-0.19	1.19*
8 x 4	-1.02*	-0.21	0.71	0.01	0.70*	-2.15*
6 x 5	0.01	2.02*	0.91*	0.01	0.46	1.01*
7 x 5	-1.15*	0.75	-0.94*	2.13*	-1.04*	1.44*
8 x 5	-0.07	0.79	0.07	-0.46	-0.20	0.18
7 x 6	0.69*	1.19	-0.39	3.53*	0.15	2.36*
8 x 6	0.25	-0.28	-0.54	-0.54	-0.21	-0.40
8 x 7	0.52	1.44	-0.73	-0.84	-0.63*	-0.30
SE($\hat{s}ij$)	0.31	0.85	0.48	0.51	0.29	0.52

*Significant from zero at .05 level of probability.

suggesting the importance of specific combining ability in determining the performance of the hybrid combinations.

The results of the specific combining ability effects described above pointed out the importance of this analysis in predicting which hybrid combinations will perform well with respect to the plant character a plant breeder desires to improve. In this study, it was found that hybrid combinations 7 x 6 and 7 x 1 were best for grain yield, kernel weight, kernel number, and protein yield. For improving protein percentage, hybrid combination 5 x 3 was the best. However, this hybrid combination was the lowest grain yielder among the hybrids.

Mean Performance of Diallel Cross in the
Segregating Generations

The mean performance of the F_2 generation of the 28 crosses is presented in Table XVII. There was a slight reduction in number of days from planting to heading compared to the F_1 generation grown in the same year. However, many crosses in the F_1 which were early or late to reach heading also showed the same response in the F_2. Reduction in plant height, head weight, grain yield, and kernel weight were also observed. The range in plant height was from 72.8 to 117.0 cm with cross 2 x 1 being the tallest entry. The range in head weight was from 50.5 to 75.6 grams. Cross 6 x 5 was highest in head weight and grain yield while 5 x 1 gave the lowest. This did not follow the same pattern as with the F_1 generation. It was also noted that there were differences in the degree of inbreeding depression for the different hybrids. As for example, hybrid 7 x 6 produced 82.9 grams in the F_1 in 1976 but produced only 42.8 grams in the F_2. Hybrid 7 x 1

TABLE XVII

MEAN PERFORMANCE OF F_2 GENERATION OF 28 CROSSES
DERIVED FROM DIALLEL CROSS OF EIGHT PARENTS
(PERKINS, OKLAHOMA 1976)

F_2 Crosses	Variable								
	HD (days)	HT (cm)	HW (g/plt)	GY (g/plt)	KW (g/100)	KN (per head)	%T (%)	%P (%)	PY (g/plt)
2 x 1	51.4	117.0	59.9	40.0	3.2	1224	66.5	13.1	5.1
3 x 1	51.8	100.6	63.9	42.5	3.3	1293	66.9	14.5	6.2
4 x 1	53.2	97.8	71.9	46.4	3.1	1498	64.6	13.0	6.0
5 x 1	52.9	98.4	50.5	30.0	2.7	1109	59.2	14.7	4.4
6 x 1	54.9	98.8	60.9	41.8	2.8	1496	68.7	12.8	5.3
7 x 1	55.5	88.7	60.5	38.2	2.0	1887	63.2	14.2	5.4
8 x 1	50.9	87.5	53.7	34.6	3.0	1139	64.1	13.2	4.6
3 x 2	50.7	92.7	57.6	37.1	3.1	1295	64.3	13.7	5.1
4 x 2	52.2	90.8	61.4	42.8	3.1	1409	68.1	11.9	5.0
5 x 2	52.4	101.9	60.6	39.1	2.8	1408	64.5	12.9	5.1
6 x 2	53.0	106.3	58.9	38.8	2.4	1639	65.8	12.8	4.9
7 x 2	54.7	103.1	62.0	40.8	2.5	1666	65.6	13.6	5.5
8 x 2	49.1	91.7	52.4	36.0	2.6	1396	68.7	12.1	4.3
4 x 3	55.1	72.8	59.4	38.2	3.1	1211	64.2	13.5	5.1
5 x 3	52.0	89.7	55.3	35.5	2.6	1357	63.4	14.5	5.1
6 x 3	54.3	91.8	63.8	41.9	2.7	1562	65.7	13.3	5.6
7 x 3	53.4	85.3	60.2	36.7	2.0	1867	60.8	13.9	5.1
8 x 3	50.9	80.3	56.8	37.8	2.7	1414	66.6	13.3	5.0
5 x 4	57.3	74.3	56.1	31.9	3.2	1039	56.0	12.8	4.0
6 x 4	62.3	75.4	56.1	38.4	3.1	1237	68.2	11.6	4.4
7 x 4	58.0	79.1	62.9	38.1	2.3	1654	60.5	13.0	4.9
8 x 4	52.6	79.9	63.2	39.1	2.6	1519	62.2	12.1	4.7

TABLE XVII (CONTINUED)

F_2 Crosses	Variable								
	HD (days)	HT (cm)	HW (g/plt)	GY (g/plt)	KW (g/100)	KN (per head)	%T (%)	%P (%)	PY (g/plt)
6 x 5	59.4	87.1	75.6	50.5	2.6	1948	66.5	12.0	6.0
7 x 5	54.6	85.0	59.3	38.3	2.4	1625	65.0	13.7	5.2
8 x 5	51.9	83.4	54.6	33.1	2.2	1539	60.6	13.8	4.6
7 x 6	58.0	88.3	68.1	42.8	1.9	2232	62.7	13.0	5.5
8 x 6	53.0	92.4	62.2	40.4	2.0	2048	65.0	12.3	5.0
8 x 7	52.6	87.8	63.0	39.1	1.8	2231	62.0	13.4	5.2
Mean	53.9	90.0	60.4	38.9	2.6	1534	64.3	13.2	5.1
LSD									
.05	1.99	25.64	NS	NS	0.46	420.82	5.47	0.87	1.15
.01	2.62	33.70	NS	NS	0.61	553.05	7.18	1.14	1.51
Parents									
1	52.0	93.1	41.5	27.7	3.9	722	66.9	15.8	4.4
2	51.5	78.9	39.1	25.7	3.7	704	65.9	13.4	3.4
3	51.6	84.8	36.5	20.6	2.6	795	55.5	15.6	3.1
4	62.0	68.2	42.5	24.4	3.4	722	56.9	12.2	3.0
5	59.6	74.2	36.6	16.9	2.6	641	44.2	15.5	2.6
6	63.8	87.1	64.1	43.2	2.8	1551	67.2	11.4	4.9
7	56.5	72.5	50.4	28.8	1.6	1791	57.2	15.5	4.4
8	49.4	76.6	46.1	30.3	2.0	1497	65.5	12.2	3.7
Mean	55.8	79.4	44.6	27.2	2.8	1053	59.9	13.9	3.7
LSD									
.05	1.79	8.35	11.00	8.17	0.37	294.04	8.49	0.90	1.02
.01	2.44	11.36	14.96	11.11	0.50	400.06	11.56	1.22	1.38

produced 67.1 grams per plant in 1976 and only 38.2 grams in the F_2.
The reduction in grain yield from F_1 to F_2 for hybrid 7 x 6 was 48%
while for hybrid 7 x 1 was only 43%. As reported by Wilson (63) the
hybrids in the F_2 generation still revealed appreciable degree of
heterosis. The pattern of response for kernel weight was similar to
the F_1. However, the values obtained were lower than in the F_1 of 1975
probably because of drought effects in the F_2 plant.

Kernel number also decreased to some extent in the F_2. Kernel
number ranged from 1039 to 2232. Cross 5 x 4 was the lowest and 7 x 6
was the highest in kernel number. However, 7 x 6 was only the third
highest grain yielder in the F_2 generation, although it was the highest
grain yielder in the F_1 generation.

The range in the threshing percentage for the F_2 data was from
56.0 to 68.7%. Cross 5 x 4 gave the lowest threshing percentage while
6 x 1 and 8 x 2 were the highest in terms of threshing percentage. It
was noted that most of the crosses in the F_2 generation gave a threshing
percentage within the range of from 60.0 to 68.7% with less variability
than in the F_1 data. The threshing percentages of the parents
associated with the F_2 revealed that parent 5 as the lowest followed
by parent 3. Parent 6 followed by parent 1 gave the highest value in
threshing percentage. It was observed that the F_2 hybrids derived from
parents 4 and 5 were the lowest in threshing percentage and that hybrids
derived from parents 1 and 6 also gave highest threshing percentage
which indicated that genes of the parents governing the percentage
threshing were transmitted to their progeny.

The percentage protein in the F_1 increased compared with the F_1
generation for some crosses. The high protein analysis in the F_2 may

be attributed to a lack of the dilution effect of carbohydrate with that of nitrogen or protein when grain yield is generally low under high fertilizer application. The application of ammonium nitrate fertilizer was followed by rainfall and subsequently droughty conditions during the grain filling periods. However, the same parents and hybrids produced high or low protein in both F_2 and F_1 generations, although the values were much higher in the F_2 than in the F_1.

Protein yield in the F_2 did not vary as much as protein yield in the F_1. It ranged from 4.0 to 6.2 grams per plant. Cross 5 x 4 gave the lowest protein yield and 3 x 1 gave the highest protein yield. Cross 3 x 1 gave significant (P <.05) and highly significant (P <.01) differences for grain yield and percentage protein, respectively, over cross 5 x 4. This probably contributed to the high protein yield of 3 x 1 and the low protein yield of 5 x 4, considering that grain yield and percentage protein determined protein yield. A considerable degree of heterosis for protein yield was still observed in the F_2. This was shown by hybrids 7 x 1 and 7 x 6 with protein yields of 5.4 and 5.5, respectively. The protein yield from midparent for hybrid 7 x 1 was 4.4 grams, while that of 7 x 6 was 4.7 grams. This resulted in heterosis of 28% for 7 x 1 and 17% for 7 x 6 in the F_2 generation.

One of the breeding procedures used to improve the performance of inbred lines is backcrossing the F_1 to either parent or both, and later on crossing the backcrosses in order to either combine or shift agronomic traits to fulfill the objectives of the breeding program. However, the amount of work and the number of plants involved become the limitations to the plant breeder not withstanding the difficulty of producing F_1 seeds. In this study, only 26 backcrosses were successfully

produced. The result of the BC generation is shown in Table XVIII. It would be observed that two doses of a high protein parent generally increased the percentage protein but reduced grain yield. For example, the F_1 of cross 2 x 1 in 1976 gave a grain yield of 34.1 grams and a protein percentage of 11.7%. Backcrossing the F_1 hybrid 2 x 1 to parent 1 in order to give a double dose of high protein parent resulted in a reduction of grain yield from 34.1 to 29.8 grams and an increase in percentage protein from 11.7% to 12.8%. This finding seemed to indicate that genes governing protein percentage could act in an additive manner. Note that the ratio of additive to nonadditive variance for protein (refer to Table XIII) was 0.41. This trend was mostly consistent for all backcrosses of F_1 of high x low protein crossed back to the high protein parent. It was not true for backcrosses of F_1 of high protein x high protein crossed back to high protein parent.

On the other hand, when F_1 crosses derived from parents both low in protein content were backcrossed to the parent with larger kernels, e.g. (6 x 4)x 4, the result did not show any apparent significant increase in grain yield nor percentage protein. However, a double dose of parents of large kernel size generally resulted in an increase in kernel size. This seemed to suggest that additive gene effect influenced kernel size.

It was further observed that plant height and heading date were generally the same in the BC as in the F_1 generation. Grain yield and protein yield still gave appreciable heterosis compared to the parents as well as the number of kernels per head. It should be observed also that like the F_1 hybrids in 1976, the BC generation was affected by

TABLE XVIII

MEAN PERFORMANCE OF BC GENERATION
(PERKINS, OKLAHOMA 1976)

BC Hybrids	HD (days)	HT (cm)	HW (g/plt)	GY (g/plt)	KW (g/100)	KN (per head)	%T (%)	%P (%)	PY (g/plt)
(2 x 1)x 1	55.1	105.3	47.1	29.8	3.0	1008	67.5	12.8	3.8
(4 x 1)x 1	56.8	81.8	48.5	27.4	2.9	949	56.1	12.0	3.3
(5 x 1)x 1	56.3	80.5	43.4	22.2	2.5	913	51.1	12.6	2.7
(6 x 1)x 1	51.4	98.1	52.7	26.2	3.0	903	49.6	13.1	3.4
(7 x 1)x 1	59.1	92.4	75.4	43.1	2.6	1747	56.6	12.6	5.4
(8 x 1)x 1	52.3	95.4	53.4	30.2	3.1	992	56.3	12.8	3.8
(4 x 2)x 2	57.1	88.4	42.6	22.4	2.3	978	52.2	12.5	2.7
(5 x 2)x 2	58.2	90.0	57.4	32.4	2.6	1269	56.2	12.1	3.9
(6 x 2)x 2	51.9	98.0	52.8	28.7	2.3	1233	53.1	12.7	3.6
(7 x 2)x 2	56.4	81.8	58.8	33.8	1.8	1836	56.8	12.5	4.2
(8 x 2)x 2	51.2	92.6	39.8	21.3	2.1	1046	53.4	11.8	2.5
(4 x 3)x 3	53.8	74.5	44.4	20.7	2.5	865	45.0	14.0	2.8
(5 x 3)x 3	56.8	82.7	56.6	24.9	2.9	846	52.8	12.3	3.0
(6 x 3)x 3	55.9	86.4	50.4	28.3	2.9	992	55.9	12.6	3.5
(7 x 3)x 3	56.8	78.0	54.8	29.3	2.3	1309	53.5	11.9	3.5
(8 x 3)x 3	59.4	64.9	31.3	16.6	2.7	608	51.6	11.7	1.9
(5 x 4)x 4	55.5	86.0	54.2	30.4	2.2	1400	56.4	12.1	3.7
(6 x 4)x 4	57.4	72.7	57.8	33.9	2.2	1596	57.8	10.7	3.6
(7 x 4)x 4	58.9	84.1	64.9	34.9	1.9	1791	54.0	12.3	4.3
(8 x 4)x 4	54.1	72.1	47.3	24.3	2.1	1337	50.5	12.4	3.0
(6 x 5)x 5	57.1	84.8	43.1	22.1	2.1	1080	51.1	12.1	2.7
(7 x 5)x 5	59.1	86.4	72.1	42.6	2.5	1726	58.9	12.5	5.3
(8 x 5)x 5	53.9	82.1	36.2	13.5	2.1	718	37.7	13.4	1.8

TABLE XVIII (CONTINUED)

BC Hybrid	HD (days)	HT (cm)	HW (g/plt)	GY (g/plt)	KW (g/100)	KN (per head)	%T (%)	%P (%)	PY (g/plt)
(7 x 6)x 6	59.9	88.9	75.9	43.4	1.6	3668	56.8	12.5	5.4
(8 x 6)x 6	55.1	86.5	49.6	28.5	1.7	1650	56.4	11.4	3.2
(8 x 7)x 7	56.8	84.8	61.1	37.8	2.0	1950	62.4	12.2	4.6
Mean	56.0	85.3	52.4	28.9	2.4	1277	54.2	12.4	3.5
LSD									
.05	3.75	11.75	12.87	9.73	0.57	452.28	10.95	1.30	1.05
.01	4.93	15.44	16.92	12.78	0.75	494.40	14.39	1.71	1.38
Parents									
1	54.3	80.8	27.2	13.8	4.1	331	50.8	14.7	2.0
2	52.8	72.4	25.9	11.3	3.1	379	42.7	14.2	1.6
3	56.9	77.5	34.2	18.2	3.0	587	52.2	12.8	2.3
4	58.5	68.7	60.0	35.2	2.7	1373	57.4	10.6	3.7
5	55.9	83.2	46.6	25.7	2.2	1170	55.0	12.7	3.2
6	59.3	91.6	46.8	26.7	1.8	1555	52.0	11.1	3.0
7	57.8	73.5	47.8	25.2	1.6	1662	51.9	13.3	3.3
8	52.1	74.5	25.8	10.7	1.4	765	41.5	12.8	1.4
Mean	56.2	77.8	39.3	20.9	2.5	978	51.1	12.8	2.3
LSD									
.05	3.47	9.74	21.18	13.98	0.75	658.07	10.27	1.21	1.50
.01	4.73	13.26	28.81	18.91	1.02	895.36	13.98	1.65	2.04

drought and greenbug damage. This probably accounted for the low grain
yield and protein yield as well as smaller kernel sizes compared to
F_1 hybrids produced in 1975. However, the data demonstrated the
accumulative action of genes governing kernel size and protein percent-
age and thus indicated the importance of backcross breeding procedure
in the improvement of these traits. On the other hand, the negative
effect on grain yield of increasing percentage protein may possibly be
offset if appreciable increase in kernel size is accomplished. This
was demonstrated by backcrossing parent 1 to F_1 hybrid 4 x 1. Parent 1
had very large kernel and high protein while parent 4 was large in
kernel size and low in protein. A double dose of parent 1 resulted in
increased grain yield, kernel weight, and percentage protein. Back-
crossing a hybrid of a small by medium kernel size to a parent with
high protein but small kernel size, e.g. (7 x 6)x 7 increased protein
percentage but reduced both grain yield and kernel size. In this case,
it seemed that the reduction in grain yield may be attributed to
reduction in kernel size.

CHAPTER V

SUMMARY AND CONCLUSIONS

Eight lines consisting of one high and one low protein line in
each of four groups classified on the basis of very large, large,
medium, and small sized kernels were crossed in a diallel system,
excluding reciprocals, in order to evaluate the relationships among
kernel size, protein content, and grain yield. Results of the study
revealed a negative significant ($P < .01$) correlation between kernel
weight and protein percentage in 1976 data but not in 1975. Head
weight and kernel number were positively and significantly ($P < .01$)
correlated with grain yield. These three variables were positively
and significantly ($P < .01$) correlated with protein yield. These find-
ings followed the same pattern as reported in the literature (1, 63).
It was also observed that kernel number was the character most related
to grain yield.

In terms of grain yield performance, hybrid combinations between
Bonar-Day x #1 and Redlan (7 x 6), gave the highest yields followed by
Bonar-Day x #1 x R-K x Korgi[2] (7 x 1) with the latter giving the highest
percentage heterosis. Kernel weight increased over their midparents
slightly when large kerneled parents were crossed with small kernel
lines with the highest positive heterosis (e.g. 7 x 6) from the mid-
parent deviations of only 24.11%. Very few hybrids showed positive
heterosis from the midparent deviation for percentage protein. The

highest came from a cross derived from lines both high in protein content (A-Wheatland-Collubi x ROKY 7)x ROKY 39 (5 x 3). This result indicated a partially dominant effect which also agreed with some findings reported in the literature (18, 26).

Results of the combining ability analyses revealed Bonar-Day x #1 (parent 7) as the highest in general combining ability effects for grain yield, kernel number, and protein yield. Parent 1 (R-K x Korgi[2]) gave the highest combining ability for kernel weight, while parent 5 (A-Wheatland-Collubi x ROKY 7) was the highest in general combining ability effects for percentage protein. There was no g.c.a. x year interaction for grain yield, kernel number, nor protein yield indicating that this general combining ability of the eight parents on these variables was not affected by the environment.

A cross between Bonar-Day x #1 and R-K x Korgi[2] (7 x 1) was the highest in specific combining ability effects for grain yield and protein yield. The highest in specific combining ability for kernel weight and kernel number were Bonar-Day x #1 x (A-Wheatland-Collubi x ROKY 7)(7 x 5) and Bonar-Day x #1 x Redlan (7 x 6), respectively. A cross between (A-Wheatland-Collubi x ROKY 7) x ROKY 39 (5 x 3) gave the highest specific combining ability for percentage protein. The variance components for g.c.a. and s.c.a. and their corresponding ratios for variables GY, KN, %P, and PY indicated the importance of specific combining ability on these traits governed by dominant gene action. Kernel weight (KW), on the other hand, was found to be governed by additive gene action.

Further assessment of the relationships of grain yield, kernel weight, and percent protein was intiated in the F_2 and BC generations.

The same patterns of response for these traits were observed in the segregating generations as in the F_1 data. An appreciable degree of heterosis in grain yield was still apparent in the F_2 with some variations among the hybrid progeny. It was also observed that increasing protein by crossing two sources of high protein genes resulted in reduction in grain yield. Likewise, it was shown that kernel weight could be increased by backcrossing to large kernel parent suggesting the importance of the accumulative action of genes.

The negative relationships between grain yield and percentage protein makes breeding for both traits difficult. Perhaps a continuous search for germplasm will yield favorable results in the future. There was an indication that breeding for kernel weight would increase grain yield. Breeding for grain yield on the basis of kernel weight may be successful by selection for lines high in heterosis and combining ability for these characters. Probably backcrossing to both parents with some form of recurrent selection may be employed to produce lines which are high in grain yield and protein and with improved kernel size.

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APPENDIXES

TABLE XIX

ANALYSES OF VARIANCE OF THE F_2 GENERATION

Source	df	HD	HT	HW	GY	KW	%T	%P	KN	PY
Rep	3	2.06	567.95	31.29	7.88	0.21	18.75	0.68	68868.48	0.03
F_2 Hybrids	27	34.63**	2623.70**	118.90	69.58	0.78**	36.51**	2.68**	411859.48**	1.05
Error	81	2.08	342.26	97.46	54.72	0.11	15.55	0.39	92198.49	0.63

**Significant at .01 level of probability.

TABLE XX

ANALYSES OF VARIANCE OF THE PARENTS ASSOCIATED
WITH THE F_2 GENERATION

Source	df	HD	HT	HW	GY	KW	%T	%P	KN	PY
Rep	3	2.69	125.81	29.57	21.61	0.09	40.93	0.43	42123.76	0.32
F_2 Parents	7	119.05**	1788.69**	338.39**	244.68**	2.47**	259.05**	13.67**	895690.87**	2.66**
Error	21	1.48	32.22	55.90	30.83	0.06	33.34	0.37	39967.91	0.48

**Significant at .01 level of probability.

TABLE XXI

ANALYSES OF VARIANCE OF THE BC GENERATION

Source	df	HD	HT	HW	GY	KW	%T	%P	KN	PY
Rep	3	5.39	60.64	640.73	221.43	0.42	127.19	1.07	455464.49	2.63
BC Hybrids	25	24.67**	315.23**	498.31**	235.97**	0.69**	119.74*	1.57*	893361.15**	3.55**
Error	75	7.34	71.90	86.28	49.26	0.17	62.40	0.89	106500.66	0.57

*, **Significant at .05 and .01 levels of probability, respectively.

TABLE XXII

STANDARD CONVERSION CHART FOR GRAIN SORGHUM
ADAPTED FROM WILSON (64)

Protein	UIR	Conc.	Protein	UIR	Conc.
7.03	28.00	0.762	10.30	39.00	0.630
7.10	28.25	0.759	10.37	39.25	0.627
7.21	28.50	0.755	10.43	39.50	0.625
7.27	28.75	0.752	10.50	39.75	0.622
7.38	29.00	0.748	10.56	40.00	0.620
7.47	29.25	0.745	10.62	40.25	0.617
7.58	29.50	0.741	10.69	40.50	0.615
7.63	29.75	0.738	10.75	40.75	0.612
7.72	30.00	0.735	10.82	41.00	0.610
7.81	30.25	0.731	10.87	41.25	0.607
7.85	30.50	0.728	10.84	41.50	0.605
7.95	30.75	0.725	11.00	41.75	0.603
8.02	31.00	0.722	11.05	42.00	0.600
8.13	31.25	0.718	11.11	42.25	0.598
8.20	31.50	0.715	11.17	42.50	0.596
8.26	31.75	0.712	11.24	42.75	0.593
8.34	32.00	0.709	11.29	43.00	0.591
8.43	32.25	0.706	11.33	43.25	0.589
8.50	32.50	0.703	11.41	43.50	0.586
8.57	32.75	0.700	11.46	43.75	0.584
8.63	33.00	0.697	11.50	44.00	0.582
8.70	33.25	0.674	11.57	44.25	0.579
8.79	33.50	0.691	11.62	44.50	0.577
8.87	33.75	0.688	11.68	44.75	0.575
8.90	34.00	0.685	11.74	45.00	0.573
9.00	34.25	0.682	11.81	45.25	0.570
9.07	34.50	0.679	11.86	45.50	0.568
9.17	34.75	0.676	11.92	45.75	0.566
9.25	35.00	0.673	11.95	46.00	0.564
9.30	35.25	0.670	12.00	46.25	0.562
9.37	35.50	0.667	12.05	46.50	0.560
9.44	35.75	0.665	12.11	46.75	0.557
9.50	36.00	0.662	12.18	47.00	0.555
9.57	36.25	0.659	12.24	47.25	0.553
9.67	36.50	0.656	12.29	47.50	0.551
9.70	36.75	0.654	12.32	47.75	0.549
9.79	37.00	0.651	12.37	48.00	0.547
9.87	37.25	0.648	12.43	48.25	0.545
9.94	37.50	0.646	12.49	48.50	0.543
9.99	37.75	0.643	12.54	48.75	0.541
10.06	38.00	0.638	12.57	49.00	0.539
10.11	38.25	0.635	12.62	49.25	0.537
10.19	38.50	0.632	12.68	49.50	0.535
10.25	38.75	0.630	12.74	49.75	0.533

TABLE XXII (CONTINUED)

Protein	UIR	Conc.	Protein	UIR	Conc.
12.79	50.00	0.531	15.49	65.50	0.423
12.82	50.25	0.529	15.56	66.00	0.420
12.87	50.50	0.527	15.65	66.50	0.417
12.94	50.75	0.525	15.74	67.00	0.413
13.00	51.00	0.523	15.81	67.50	0.410
13.05	51.25	0.521	15.89	68.00	0.407
13.08	51.50	0.519	15.95	68.50	0.404
13.12	51.75	0.517	16.04	69.00	0.401
13.19	52.00	0.515	16.11	69.50	0.398
13.24	52.25	0.513	16.19	70.00	0.395
13.29	52.50	0.511	16.25	70.50	0.392
13.33	52.75	0.509	16.32	71.00	0.389
13.37	53.00	0.507	16.41	71.50	0.386
13.42	53.25	0.505	16.45	72.00	0.384
13.45	53.50	0.504	16.54	72.50	0.381
13.49	53.75	0.502	16.61	73.00	0.378
13.55	54.00	0.500	16.70	73.50	0.375
13.60	54.25	0.498	16.75	74.00	0.373
13.66	54.50	0.496	16.82	74.50	0.370
13.70	54.75	0.494	16.89	75.00	0.367
13.75	55.00	0.492	16.95	75.50	0.364
13.80	55.25	0.490	17.02	76.00	0.362
13.82	55.50	0.489	17.08	76.50	0.359
13.87	55.75	0.487	17.17	77.00	0.356
13.93	56.00	0.485	17.25	77.50	0.353
13.99	56.25	0.483	17.30	78.00	0.351
14.01	56.50	0.482	17.37	78.50	0.348
14.06	56.75	0.480	17.44	79.00	0.346
14.10	57.00	0.478	17.50	79.50	0.343
14.12	57.25	0.477	17.55	80.00	0.341
14.19	57.50	0.473	17.63	80.50	0.338
14.25	57.75	0.473	17.69	81.00	0.336
14.30	58.00	0.471	17.75	81.50	0.333
14.36	58.50	0.468	17.80	82.00	0.331
14.45	59.00	0.464	17.87	82.50	0.328
14.55	59.50	0.461	17.95	83.00	0.325
14.61	60.00	0.458	18.00	83.50	0.323
14.70	60.50	0.454	18.06	84.00	0.320
14.81	61.00	0.451	18.13	84.50	0.317
14.85	61.50	0.448	18.19	85.00	0.315
14.93	62.00	0.445	18.25	85.50	0.312
15.05	62.50	0.441	18.31	86.00	0.310
15.12	63.00	0.438	18.38	86.50	0.307
15.19	63.50	0.435	18.45	87.00	0.304
15.25	64.00	0.432	18.50	87.50	0.302
15.32	64.50	0.429	18.57	88.00	0.299
15.42	65.00	0.426	18.67	88.50	0.296

VITA $\frac{1}{2}$

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