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GENETIC AND ENVIRONMENTAL CONTROL OF PROTEIN QUANTITY AND QUALITY AND THEIR RELATIONSHIPS WITH CERTAIN AGRONOMIC CHARACTERS IN *SORGHUM BICOLOR* (L.) MOENCH

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Submitted to the Faculty

of

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by

Frederick Clinton Collins

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of

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TABLE OF CONTENTS

Page

LIST OF TABLES v

ABSTRACT ix

SECTION I. COMBINING ABILITY FOR YIELD, PROTEIN, AND LYSINE AND THEIR RELATIONSHIPS WITH CERTAIN AGRONOMIC CHARACTERS IN SORGHUM BICOLOR (L.) MOENCH. 1

Introduction. 1
Review of Literature. 2
Materials and Methods 7
Four by Twelve Incomplete Diallel. 7
Nine Parent Diallel. 11
Results and Discussion. 15
Four by Twelve Parent Incomplete Diallel 15
Nine Parent Diallel. 29
Summary and Conclusions 46
Four by Twelve Parent Incomplete Diallel 46
Nine Parent Diallel. 48
Bibliography. 51

SECTION II. INHERITANCE OF PERCENTAGE PROTEIN AND ITS RELATIONSHIP TO OTHER CHARACTERS IN SORGHUM BICOLOR (L.) MOENCH 55

Introduction. 55
Review of Literature. 55
Materials and Methods 57
Results and Discussion. 60
Summary and Conclusions 69
Bibliography. 72

SECTION III. ENVIRONMENTAL EFFECTS ON PERCENTAGE PROTEIN IN SORGHUM BICOLOR (L.) MOENCH 74

Introduction. 74
Review of Literature. 75
Materials and Methods 78
Experiment I: Plant to Plant Variation Within a Line 78
Experiment II: Effects of Bagging and Flag Leaf Removal. 79
Experiment III: Effect of Harvesting at Various Stages 80
Experiment IV: Effects of locations and Years. 81

TABLE OF CONTENTS
(Continued)

Page

Results and Discussion 82
Experiment I: Plant to Plant Variation Within a Line 82
Experiment II: Effects of Bagging and Flag Leaf Removal 84
Experiment III: Effect of Harvesting at Various Stages 88
Experiment IV: Effects of Locations and Years 90
Summary and Conclusions 95
Bibliography 97

APPENDIX 99

VITA 109

LIST OF TABLES

Table | Page

1. Pedigree and origin of each pollinator parent used in the incomplete diallel grown in 1967 8

2. Pedigrees and origins of the sorghum lines used as parents in the nine parent diallel grown in 1968 12

3. Analyses of variance of grain yield, percentage protein, protein yield, percentage lysine, and lysine yield measured from 65 sorghum genotypes of the incomplete diallel grown in 1967. 16

4. Combining ability analyses of variance and estimates of narrow sense heritabilities of grain yield, percentage protein, protein yield, percentage lysine, and lysine yield measured from the incomplete diallel of 48 F_1 hybrids grown in 1967. 18

5. Estimates of general and specific combining ability effects for grain yield of 48 F_1 hybrids of the incomplete diallel grown in 1967. 19

6. Estimates of general and specific combining ability effects for percentage protein of 48 F_1 hybrids of the incomplete diallel grown in 1967. 21

7. Estimates of general and specific combining ability effects for protein yield of 48 F_1 hybrids of the incomplete diallel grown in 1967. 22

8. Estimates of general and specific combining ability effects for percentage lysine of 48 F_1 hybrids of the incomplete diallel grown in 1967. 23

9. Estimates of general and specific combining ability effects for lysine yield of 48 F_1 hybrids of the incomplete diallel grown in 1967. 24

10. Percent heterosis of 48 F_1 hybrids for five characters measured from the incomplete diallel grown in 1967 26

11. Simple correlation coefficients among five characters of 65 sorghum genotypes of the incomplete diallel grown in 1967. . . 28

LIST OF TABLES
(Continued)

Table Page

12. Percentage protein of inbred and actual F_1 seed of diallel crosses among nine parents including reciprocals 30

13. Analyses of variance for 13 characters measured from the sorghum diallel of nine parents and 36 F_1 hybrids grown in 1968. 32

14. Combining ability analyses of variance and heritability estimates for 13 characters measured from the sorghum diallel of nine parents and 36 F_1 hybrids grown in 1968. 33

15. Estimates of general combining ability effects of nine parents for 13 characters measured from the nine parent sorghum diallel grown in 1968. 35

16. Estimates of specific combining ability effects of 36 F_1 hybrids for 6 characters measured from the nine parent sorghum diallel grown in 1968. 37

17. Estimates of specific combining ability effects of 36 F_1 hybrids for seven characters measured from the nine parent sorghum diallel grown in 1968. 38

18. Percent heterosis of the F_1 hybrids for six characters measured from the nine parent sorghum diallel grown in 1968. . 40

19. Percent heterosis of the F_1 hybrids for seven characters measured from the nine parent sorghum diallel grown in 1968. . 42

20. Simple correlation coefficients among 13 characters measured from the diallel of nine parents grown in 1968. . . . 45

21. Analysis of variance for percentage protein of 12 populations of parents, F_1's and F_2's. 61

22. Frequency distribution of percentage protein values of 12 populations of parents, F_1's and F_2's 62

23. Means, phenotypic, environmental, and genetic variances and heritability estimates for percentage protein of 14 populations of parents, F_1's and F_2's. 63

24. Number of gene pairs for percentage protein in five F_2 populations estimated by the Castle-Wright formula and the Burton formula 65

25. Phenotypic correlation coefficients of percentage protein with eight other characters in 12 populations of parents, F_1's and F_2's. 66

LIST OF TABLES
(Continued)

Table Page

26. Means and variances of single seed analysis for percentage protein of three plants of Martin, 1884, 1884 × MRT F_1, and 1884 × MRT F_2. 68

27. Percentage protein of seven selections of Line 0819 grown in 1967. 83

28. Analysis of variance of seven selections from Line 0819 for percentage protein 83

29. Pooled analyses of variance for grain yield, percentage protein, and 100 seed weight of the effects of bagging and flag leaf removal experiment grown in 1967 and 1968. 85

30. Treatment means for grain yield, protein yield, percentage protein, and 100 seed weight of the effects of bagging and flag leaf removal experiment grown in 1967 and 1968. 86

31. Varietal means for grain yield, protein yield, percentage protein, and 100 seed weight of the effects of bagging and flag leaf removal experiment grown in 1967 and 1968. . . . 87

32. Analysis of variance for percentage protein of four sorghum genotypes harvested at seven different stages of maturity in 1967. 89

33. Means of percentage protein of seven harvest stages of four sorghum genotypes grown in 1967. 89

34. Means of percentage protein of four sorghum genotypes harvested at seven stages of maturity in 1967. 90

35. Pooled analyses of variances for grain yield percentage protein and protein yield of 11 sorghum genotypes grown in three locations in 1967 and 1968 91

36. Yearly means of grain yield, percentage protein, and protein yield of 11 sorghum genotypes grown in 1967 and 1968 at three locations. 91

37. Means of grain yield (kg/ha) of 11 sorghum genotypes grown at three locations in 1967 and 1968. 92

38. Means of percentage protein of 11 sorghum genotypes grown at three locations in 1967 and 1968. 93

39. Means of protein yield (kg/ha) of 11 sorghum genotypes grown at three locations in 1967 and 1968. 94

LIST OF TABLES
(Continued)

Appendix Table | Page

A1. Mean values of eight characters measured from 65 sorghum genotypes of the incomplete diallel grown in 1967. 99

A2. Means of six characters measured from the sorghum diallel of nine parents and 36 F_1 hybrids grown in 1968. 102

A3. Means of seven characters measured from the sorghum diallel of nine parents and 36 F_1 hybrids grown in 1968. 104

A4. Mean squares of the analyses of variance of Wr-Vr values from 13 characters of the nine parent diallel grown in 1968 106

A5. Means for grain yield, protein yield, percentage protein, and 100 seed weight of five varieties subjected to four bagging treatments which were carried out in 1967 and 1968 . . 107

A6. Means of percentage protein of four sorghum genotypes harvested at seven stages of maturity in 1967. 108

ABSTRACT

Collins, Frederick Clinton. Ph.D., Purdue University, June 1969. Genetic and Environmental Control of Protein Quantity and Quality and Their Relationships with Certain Agronomic Characters in Sorghum bicolor (L.) Moench. Major Professor: Robert C. Pickett.

Combining ability for grain yield and protein quantity and quality of the grain was investigated in nineteen sorghum lines and in F_1 hybrids obtained from certain crosses among the nineteen lines. In 1967 an incomplete diallel was grown which consisted of inbred parents and crosses among 12 lines used as males and four lines used as females. In 1968 a nine parent diallel was grown which consisted of the parents and one set of F_1's. Grain yield, percentage protein, percentage lysine, protein yield, and lysine yield were measured in both studies. In addition, date of flowering, leaf number, height, flag leaf area index, head exertion, head length, yield per head, and 100 seed weight were examined in the 1968 study. Significant differences among genotypes were found for all characters. Grain yield ranged from 3088 to 15863 kg/ha, protein varied from 9.18 to 18.22 percent; and the range of lysine was from 1.25 to 2.74 percent. A highly significant general combining ability (GCA) variation was found for every character in the two studies while significant variation due to specific combining ability (SCA) was found only in the 1968 study and it existed for every character. Grain yield and percentage lysine had GCA:SCA mean square ratios of less than 10:1 and percentage protein had a 31:1 ratio.

Many F_1's yielded significantly more than either parent and some had significantly higher levels of protein than their parents. Among these were hybrids whose parents were superior for yield and protein level. Percentage protein was negatively correlated with lysine and yield. Percentage lysine and yield were unrelated in 1967 but were positively associated in 1968. These results suggest that both additive and non-additive gene action influenced yield, protein, and lysine and that high levels of protein and lysine can be incorporated into high yielding materials.

The inheritance of protein level was studied in five segregating populations, their F_1's, and parents. Four lines were involved; three had higher levels of protein while the fourth was low in protein. The F_2 variances indicated that the lines all had different genes for protein which were few in number and appeared to be at least partially dominant for high protein. The protein level was positively correlated with tiller number and negatively associated with date of flowering. A highly significant negative correlation existed between protein level and head weight in every F_2 population. Results of single seed analysis from seed of parents, F_1 plants, and F_2 plants failed to show evidence of genetic variation which suggest that the environment has sufficient influence on a plant to suppress the expression of genetic differences in the seed of that plant.

Four experiments were conducted to determine the effects of specific environmental treatments on protein. Comparison of the protein values of individual plants with those of their progeny indicated that a more reliable estimate of protein can be obtained from a sample of several plants. Bagging the head and removing the flag leaf significantly

decreased yield while percentage protein was increased slightly by bagging the head. Grain had a high level of protein when it was harvested in the milk stage. The protein level in grain harvested four months later was similar to the protein level of grain just matured. Growing eleven genotypes at three locations for two years disclosed a significant interaction of genotypes × locations × years and it indicated the necessity of evaluating material for protein at the location of intended utilization for more than one year.

SECTION I

COMBINING ABILITY FOR YIELD, PROTEIN, AND LYSINE AND THEIR RELATIONSHIPS WITH CERTAIN AGRONOMIC CHARACTERS IN *SORGHUM BICOLOR* (L.) MOENCH

SECTION I

COMBINING ABILITY FOR YIELD, PROTEIN, AND LYSINE AND THEIR RELATIONSHIPS WITH CERTAIN AGRONOMIC CHARACTERS IN *SORGHUM BICOLOR* (L.) MOENCH

Introduction

Considerable attention is being given to improving the nutritional value of cereals, including sorghum which is a major source of food for millions of people in the world. The nutritional value of the grain can be increased by either increasing the quantity of protein or by increasing the quality of that protein which is already present; the ultimate objective is to increase both. In order to improve the quality of sorghum protein, the proportion of lysine must first be increased because it is the most limiting amino acid in sorghum protein.

A wide range in protein and lysine contents exists among lines of the world collection of sorghum and both characters appear to be under genetic control. In order to incorporate better protein quantity and quality into the grain sorghums efficiently, it is necessary to determine the type of gene action which controls their expression. Since commercial grain sorghum production in the United States is based on the use of hybrids, the combining ability for protein quantity and quality should be measured by the performance of hybrids in such a manner that gene action can be partitioned into additive and non-additive effects. Therefore, this study was designed to investigate the combining ability for protein and lysine content and their

relationships with certain agronomic characters. These included date of flowering, leaf number, height, flag leaf area index, head exertion, head length, grain yield, yield per head, and seed weight.

Review of Literature

Early evidence of genetic improvement in protein content was given by Hayes and Garber (16) when they showed that the protein content in corn could be increased by selection. Frey (12) found in his protein inheritance study in maize that low percentage protein was dominant which may have been partially caused by higher yields due to hybrid vigor. In the Illinois long term recurrent selection experiment for protein in corn, Woodworth *et al*. (43) reported that the percentage protein was increased from 10.92 percent to 19.45 percent by selecting for high percentage protein and it was decreased from 10.92 percent to 4.91 percent by selecting for low percentage protein after 50 generations of recurrent selection. Johnson *et al*. (20) investigated the behavior of protein in wheat; they found Atlas 66 to be much higher in percentage protein than other varieties and they felt that this increased protein content of Atlas 66 was due to the enhanced ability of that variety to translocate the nitrogen from the leaves to the grain. Mahaderappa (25) studied the inheritance of protein content in *Pennisetum typhoides* by use of a diallel cross of five parents which ranged from 12.40 to 14.95 percent protein and found that, in general, the performance of F_1's were either equal to or above the mid parent value; there was also evidence of epistasis.

There has been a considerable amount of evidence accumulated that there is a wide range in percentage protein among sorghum varieties

and that percentage protein is under genetic control. Miller et al. (28) reported variations of 5.9 to 12.8 percent protein in Kansas grain sorghum varieties. Deyoe and Shellenberger (11) analyzed 15 different hybrids for protein content and found a range of 8.65 to 12.50 percent. Liang (22) found general combining ability to be significant for percentage protein and he also found the protein content of the hybrids was significantly lower than the superior parents. The Jinks-Hayman method of diallel analysis was used by Liang et al. (23) to study gene action in a 6 variety diallel; they concluded that protein content was partially dominant; however, the regression coefficient in the Wr,Vr graph was significantly less than one which indicated the presence of either epistasis or correlated gene distribution or both. Their analysis also indicated that there were two groups of genes for the control of protein content. Malm (26) crossed eight exotic lines which varied from 10.8 to 15.5 percent protein on to Martin, Combine Kafir 60, Wheatland, and Redlan male steriles. General and specific combining ability for percentage protein was estimated from the performance of the F_1's; general combining ability was 17.5 times greater than the specific combining ability which indicated that the additive gene action was most important. He also found that Martin contributed more to protein content than the other female parents. Campbell and Picket (7) reported a genotypic range of 11.7 to 16.3 percent protein among lines of the world collection of sorghum used in their study.

Protein quality research in cereals was greatly stimulated by the discovery by Mertz and Nelson (27, 30, 31, 32) that opaque-2 and floury-2 mutants of maize contained almost twice the normal proportions of lysine and tryptophan. They found floury-2 also to have a higher

methionine level. An added bonus came when they found some of the progeny of a cross of a Illinois high protein line with the double mutant to be high in protein quantity and quality. Johnson et al. (20) found selections of the high protein variety, Atlas 66, which were higher than normal in lysine content. Villegas et al. (40) investigated the lysine content in several species of wheat, rye, and Triticale; they found protein values as high as 24.8 percent and lysine values up to 4.26 percent; some species had a good combination of protein and lysine. Deyoe and Shellenberger et al. (11) reported significant differences in lysine content among 15 varieties of sorghum which ranged from 1.81 to 2.49 percent lysine as a percentage of the protein. Campbell and Pickett (7) found a range of 1.64 to 2.52 percent lysine among 18 inbreds of the world collection of sorghum.

Mitchell et al. (29) found a negative relationship between protein quantity and quality in corn. The proportion of zein, which has almost no lysine or tryptophan, increased linearly (r=0.95) with increases of total protein up to 14 percent; at higher protein levels the regression departed from linearity. Bhatty et al. (5) obtained similar results in wheat; they calculated a -0.72 correlation coefficient between protein and lysine percentage. In a study of 25 inbreds of sorghum Bressani and Rios (6) reported a positive relationship of protein and lysine (r=0.5623). Waggel et al. (42) measured the nutritive value of high and low protein content grain sorghum by rat performance and amino acid assays. The high protein (11.8 percent) grain had a higher percentage of all 17 amino acids studied than the low protein grain (7.9 percent); however, the sulfur bearing amino acids, threonine, and the diabasic amino acids, especially lysine, were lower in the high protein grain

than in the low protein grain when they were calculated on an equal nitrogen basis. The nutritive value as measured by rat growth was also lower for the high protein sorghum when they were fed the two on the basis of equal nitrogen. If the two were fed on an equal basis of pound for pound of the grain, the nutritive value of the high protein was superior. Waggle et al. (41) later found that the level of nitrogen fertilization affected the amino acid ratios. While nitrogen fertilization significantly increased protein, the proportions of lysine, histidine, arginine, threonine, and glycine were lowered and the other amino acids increased in proportions. Although Campbell and Pickett (7) found that nitrogen fertilization did significantly increase protein content, it did not significantly affect the lysine content of the protein. A negative correlation of -0.12 was reported for the protein and lysine association.

An inverse relationship has been reported between yield and protein content in corn by Hayes and Garber (16), Frey (13), and Aruand et al. (1). However, the latter group of workers did find a positive association between the two during one season. They were able to find hybrids that were both high yielding and contained a high protein content. An interesting aspect of the study by Hayes and Garber was that they found little, if any, effect of foreign pollen on the percentage protein of the F_1 seed. Fröst and Ellerstrom (14) investigated the causes of the increased protein content in tetraploid rye and found strong negative correlations between protein and fertility of the flower and between protein and 1000 seed weight. The degree of shrinkage of the seed was positively correlated with protein content. A nonsignificant negative association of yield and protein in sorghum was reported by Liang (22).

However, in the study made by Malm (26) protein was negatively correlated with yield and starch. Protein was positively correlated with seed weight and, at the same time, there was a positive correlation between yield and seed weight. Lowe (24) found an inverse relationship between yield and protein content when he measured them from the performances of varieties and hybrids grown under fallow and irrigated conditions. Varieties had a lower grain yield and higher protein content than hybrids and irrigated conditions increased yield and decreased protein content when compared with fallow conditions. This may be explained by Bartel's (2) observations; he found hybrids occasionally had a larger seed size than that of the larger seeded parent and the main effect was on the endosperm. Since the endosperm has a lower percentage protein as shown by Rooney and Clark (36) and Normand et al. (34), the hybrids would be expected to have a lower percentage protein if their seed size was larger.

Heterosis for earlier blooming and increased tillering, height, stem size, leaf size, head size, and production of grain and forage has been reported by Quinby (35). Most reports have indicated general combining ability to be more important than specific combining ability for these characters which suggests that the genes controlling them are mainly additive in their expression as shown by the agreement of the conclusions reached by Kambal and Webster (21), Chiang and Smith (8,9), Beil and Atkins (4), Liang (22), Liang et al. (23), Malm (26), and Niehaus and Pickett (33). However, striking heterosis was noted, particularly by the Niehaus and Pickett study, in crosses between very diverse materials.

Materials and Methods

This study consisted of two parts. In the first part an incomplete form of a diallel cross of 12 fertility restorer lines crossed onto four male sterile lines was used in 1967 to give preliminary information about the combining ability for percentage protein and lysine. A nine parent diallel was used in 1968 in the second part of this study to give a more complete assessment of the combining ability for yield, percentage protein, and lysine of the nine selected lines used as parents.

Four by Twelve Incomplete Diallel

Four male sterile lines which were widely used by the hybrid seed industry were chosen to evaluate combining ability. These were Martin, Combine Kafir 60, Wheatland, and Redlan.

The pollinator parents were 12 lines selected to represent the morphological diversity found in about 500 lines of the world collection of sorghum that flowered at Purdue in 1965. The pedigree and origin of each pollinator line is shown in Table 1. The 1963 Hyderabad nursery number is used in this thesis to identify the pollinator parents because lines of the world collection of sorghum grown at Purdue in previous years to 1968 had only the 1963 Hyderabad nursery number for identification. The India Sorghum (I.S.) identifications, which are presently being used, are given in Table 1 to allow comparison of the 1963 Hyderabad and I.S. identifications.

Crosses of the 12 pollinator lines onto each of the four male sterile lines were made during the summer of 1966. The 16 parents, 48 crosses, and RS 610 were planted at the Purdue University Agronomy

Table 1. Pedigree and origin of each pollinator parent used in the incomplete diallel grown in 1967†.

1963 Hydera-bad No.	I.S. No.	Group	Pedigree	Seed Source
0305	8168	23-Caffrorum-Darso	EC 21362 G31	IARI, India
0786	8120	36-Caudatum-Bicolor	a-112-3	Japan
0819	2319	33-Caudatum	P.I. 217837 Lawalli White Q2-3-25	Maryland
1150	1220	8-Nervosum-Kaoling	AS5227	Tsinan, China-Coimbatore
1360	8255	25-Caffrorum-Foxburghii	EC 21454 SB256	IARI, India
1457	0718	10-Bicolor	African Millet	Mexico
1814	0271	48-Durra-Kaura	Unknown	Unknown
1884	0508	34-Caudatum-Kaura	R F Y E 3-4-2	Mexico
2486	3935	34-Caudatum-Kaura	SA9850 Big Seed Yel. End.	California
5075	8005	12-Dochna	Cane Hony Lot #36175	Japan
5126	8301	34 Caudatum-Kaura	SA9129-26-4 DD SS Wx	Texas
5217	6898	27 Caffrorum-Feterita	18 DS 18	Sudan

†This information was obtained from "List of Pedigrees for World Sorghum Nursery."

Farm on May 4, 1967. The 65 entries were replicated four times in a randomized complete block design. Each plot consisted of two rows 38 inches apart and 15 feet in length. Each was hand-thinned to a stand of approximately 120,000 plants per acre when the plants were around four inches tall. Weed control was by cultivation. The soil type was a Chalmers silty clay loam. Anhydrous ammonia at the rate of 194 pounds per acre and 8-32-16 at the rate of 170 pounds per acre distributed in the row were applied before planting. The weather in May was wet and cold; June was dry and warm; July and August were also dry but the temperature was abnormally cool.

The following characters were measured on each plot:

Heading Date - date when heads had protruded from the boot of 50 percent of the plants in the plot.

Height - in centimeters measured at maturity.

Leaf Number - average number of leaves from three random plants in the plot.

Grain Yield - in kilograms per hectare, measured from 10 feet taken from the center of each row of the plot.

Percentage Protein - the proportion of nitrogen determined by microkjeldahl multiplied by 6.25.

Percentage Lysine - lysine determined by ion-exchange column chromatography and reported as a percentage of the protein.

Protein Yield - in kilograms per hectare, calculated by multiplying grain yield by percentage protein.

Lysine Yield - in kilograms per hectare, calculated by multiplying protein yield by percentage lysine.

Although the value representing percentage protein is actually the

proportion of "crude" protein of the grain, the term "percentage protein" will be used throughout this thesis.

Only the means were calculated from the data of the first three characters and these are shown in Appendix Table 1 along with the means of the remaining five characters for each of the 65 entries. The data for the last five-named characters was analyzed by analysis of variance to determine whether or not differences existed among entries. The measurements of the 48 F_1 hybrids were then analyzed for combining ability using statistical methods of Comstock and Robinson (10) for Design II experiments. One assumption of this model is that the parents were randomly chosen. Since the female parents did not meet this requirement and since there was also doubt about the validity of this assumption for the male parents, the analyses were also performed on the data using a fixed model. According to Sprague and Tatum (38), general combining ability (GCA) designates the average performance of a line in hybrid combination and specific combining ability (SCA) designates those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Estimates of narrow sense heritabilities were derived by dividing that component of variance due to additive genetic effects by the total variance of the crosses. The GCA component of variance was used as the estimate of additive genetic variance. General and specific combining ability effects were estimated from the F_1 performance by utilizing the method used by Beil and Atkins (4) to obtain values for the relative magnitude of each effect. Heterosis was determined by dividing the mean of the F_1 by the mean of the superior parent for each character. Levels of significance of heterosis were obtained by

comparing the actual means by the proper LSD. Simple correlations were calculated between characters to show the magnitude of their relationship. Correlation coefficients were tested for significance by comparing them to values in Table 7.6.1 of Snedecor (37).

Nine Parent Diallel

The parents used in this portion of the study were chosen primarily to exhibit a wide range in protein content but yet being as different for other morphological traits as possible. The pedigrees and origins of the nine lines used as parents are shown in Table 2. The 1963 Hyderabad numbers are also used in this portion of the study to identify five of the parents. Lines 0819, 1884, Martin, Combine Kafir 60, Wheatland, and Redlan are common to both portions of the study. Again RS 610 was included as a check.

Crosses among the nine parents were made in the greenhouse during the winter of 1966-67 and in the field in the summer 1967. Where it was possible, F_1 seed were obtained by using male sterile lines and, in several cases, emasculation was accomplished by using the hot water technique developed by Stephens and Quinby (39). But in nearly 50 percent of the crosses, emasculation had to be done by hand because the hot water treatment was not successful when used on lines 0355, 0819, and 0793. Since 0355 did not shed very much pollen, it had to be used as the female in order to obtain sufficient amounts of F_1 seed. Lines 0819 and 0793 were excellent pollen producers but were difficult to use as females. The F_1 seed of each cross, including the reciprocals, were analysed for protein content to give an indication of the dosage effects of genes controlling protein formation in the endosperm.

Table 2. Pedigrees and origins of the sorghum lines used as parents in the nine parent diallel grown in 1968†.

1963 Hydera-bad No.	I.S. No.	Group	Pedigree	Seed Source
0355	1259	12-Dochna	AS 5781 Huan-sa-phaung-ah-lpysu	Burma-Coimbatore
0793	0075	33-Caudatum	C.I. 623 Spur Feterita	Mexico
0819	2319	33-Caudatum	P.I. 217837 Lawalli White Q2-3-25	Maryland
1884	0508	34-Caudatum-Kaura	R F Y E 3-4-2	Mexico
5187	8364	22-Caffrorum	SA 3126 4 dwf-CK60	USA
			Martin (MRT)	USA
			Combine Kafir 60 (CK60)	USA
			Wheatland (WHT)	USA
			Redlan (RDL)	USA

†The pedigrees and origins of the first five lines were obtained from "List of World Sorghum Nursery."

The nine parents, 36 F_1 crosses, and RS 610 were planted at the Purdue University Agronomy Farm on May 1, 1968. Shortly after planting, it started raining and by the end of the month, 8 inches of rain had fallen. Due to flooding of the field and quite cool temperatures, stands were very poor. So, the entire experiment was replanted as completely as the remnant seed would permit. Each entry was replicated four times in a randomized complete block design. A plot consisted of four rows 30 inches apart and 12 feet long. Each was thinned to approximately 90,000 plants per acre. Atrazine and Ramrod were applied

at 2.5 and 1.5 pounds per acre, respectively, for weed control. Two cultivations were required. Temperature and moisture were adequate for good growing conditions throughout the season with the exception of May. The soil type was a Chalmers silty clay loam. The field was spring plowed. Two hundred and fifty-nine pounds actual nitrogen was applied, half in the form of urea and half in the form of ammonium nitrate the week prior to planting.

The following 13 characters were measured from plants of the two center rows of each 4-row plot:

Flowering - date when 50 percent of the plants were in bloom. July 1 was used as the base date because of the two different planting dates. Plants from the later planting flowered about one week later.

Leaf Number - average number of leaves obtained from three plants.

Height - in centimeters, measured at maturity.

Leaf Area Index of the flag leaf - in square centimeters, calculated by multiplying the length times the width times 0.60†.

Head Exertion - in centimeters, measured from the collar of the flag leaf to the lowermost panicle node.

Head Size - in centimeters, measured from the bottom panicle node to the uppermost floret.

Grain Yield - in kilograms per hectare, measured from the 10 feet of each of the two center rows of the plot. The grain contained seven to eight percent moisture when it was weighed.

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†Beckman, W. P. 1969. Leaf characteristics in relation to yield and certain other characters in a diallel cross of 8 lines of Sorghum vulgare Pers. Ph.D. Thesis, Purdue University.

Yield per Head - in grams, calculated by dividing grain yield of each plot by the number of heads harvested.

Percentage Protein - calculated by multiplying 6.25 by the proportion of nitrogen determined from microkjeldahl.

Protein Yield - in kilograms per hectare, calculated by multiplying percentage protein by grain yield.

Percentage Lysine - determined from ion-exchange column chromatography and based as a percentage of protein.

Lysine Yield - in kilograms per hectare, calculated by multiplying protein yield by percentage lysine.

The data for each character was first analyzed for the presence of significant genotypic differences. Then it was further analyzed for general (GCA) and specific (SCA) combining ability using "method 2 - model I" described by Griffing (15). This method utilizes the parents and one set of F_1's but not reciprocal F_1's and the genotypes and block effects are constants. Therefore, it will not be valid to make inferences, which are derived from the results of this diallel, to other sorghum populations. Heritability was estimated by dividing GCA by total variance. The data was also analyzed using the Jinks-Hayman (Vr,Wr) method (18,19). This method makes certain assumptions as follows:

1. Inheritance is wholly diploid.
2. Parents are homozygous.
3. There are not maternal effects.
4. The alleles at different loci are distributed independently in the different parents.
5. There is no interaction of alleles at different loci.

6. Each locus has only two alleles.

When any of these assumptions are not met, there is a more or less drastic change which is usually characteristic of the cause. An analysis of variance of the Wr minus Vr values was performed on each character as a method described by Hayman (17) for testing whether the data meet assumptions. Simple correlation coefficients were calculated to indicate the magnitude of relationships between characters. Again, Table 7.6.1 of Snedecor (37) was used to determine the level of significance of the coefficients.

Results and Discussion

Four by Twelve Parent Incomplete Diallel

Results of the analysis of variance for each character (Table 3) indicated that there was a highly significant effect of genotypes on each character. Blocks (replicates) contained significant amounts of environmental variation in all cases, particularly percentage lysine where the block variation was about 47 times greater than that due to genotypes. The precision of measuring characters was greatest for percentage protein and least for lysine yield as estimated by the coefficients of variation (C.V.). The high C.V. value for the latte was probably due to the confounding of error variance in measuring grain yield and percentage lysine. Grain yield ranged from 3088 to 9286 kilograms per hectare; percentage protein ranged from 10.23 to 15.53 percent; percentage lysine ranged from 1.25 to 1.97 percent of the protein; protein yield of the grain ranged from 573.9 to 1192.5 kilograms per hectare; and lysine yield ranged from 7.66 to 18.58 kilograms per hectare.

Table 3. Analyses of variance of grain yield, percentage protein, protein yield, percentage lysine, and lysine yield measured from 65 sorghum genotypes of the incomplete diallel grown in 1967.

Source of Variation	D.F.	Mean Squares				
		Grain Yield	% Protein	Protein Yield	% Lysine	Lysine Yield
Blocks	3	1,489,273**	3.37**	31,398**	4.70**	62.71**
Genotypes	64	2,643,932**	5.37**	40,083**	0.10**	10.89**
Error	192	378,651	0.49	7,084	0.06	5.07
C.V.		15.77%	5.44%	16.87%	16.03%	29.02%

**Significant at the .01 level.

Since genotypic differences were indicated by the analysis of variance, the performance of the 48 F_1 hybrids were analyzed in order to estimate general (GCA) and specific (SCA) combining ability effects. Results of the combining ability analysis of variance are shown in Table 4. The male by female interation, which was a measure of SCA, was not significant for any character. Therefore, the testing of expected mean squares was similar regardless of whether the parents were considered fixed or random. There was a highly significant effect of male parents for each character while the female parents significantly affected only the grain yield, percentage protein, and protein yield and did not significantly influence the percentage lysine or lysine yield of the F_1 progeny. These results were interpreted to mean that additive gene action was very important in controlling the level of expression of each character. Estimation of the amount of additive gene action was determined by equating it to the GCA component of variation.

Narrow sense heritabilities (Table 4) were estimated by dividing the GCA components of variation by the total variation. Where male and female effects were both significant, the two GCA components were added together. These estimates of heritability for grain yield and percentage protein were quite high while that for percentage lysine was very low.

Estimates of the GCA and SCA effects for grain yield are shown in Table 5. F_1 hybrids having Redlan as their female parent tended to yield the most while those having Martin as their female parent tended to yield the least. Wheatland crosses appeared better than Combine Kafir 60 crosses. The rank of female effects was as expected from previous work at Purdue. Crosses involving male lines 1150 and 0305 were vastly superior to those of the 10 other male lines. Lines 1360,

Table 4. Combining ability analyses of variance and estimates of narrow sense heritabilities of grain yield, percentage protein, protein yield, percentage lysine, and lysine yield measured from the incomplete diallel of 48 F_1 hybrids grown in 1967.

Source of Variation	D.F.	Mean Squares				
		Grain Yield	% Protein	Protein Yield	% Lysine	Lysine Yield
G.C.A. (Male effects)	11	4,933,107**	15.00**	67,009**	0.22**	19.93**
G.C.A. (Female effects)	3	3,815,882**	13.55**	45,140**	0.05	4.61
S.C.A. (Male × Female effects)	33	342,813	0.62	6,965	0.05	3.52
Error	144	414,622	1.16	8,031	0.06	4.51
Heritability†		70	74	50	12	21

**Significant at the .01 level.
†Heritability estimates in the narrow sense.

Table 5. Estimates of general and specific combining ability effects for grain yield of 48 F_1 hybrids of the incomplete diallel grown in 1967.

Males	Females				General Effects of Males
	Martin	CK60	Wheatland	Redlan	
	Specific Effects				
0305	0.12	0.05	0.19	0.30	0.16
0786	-0.21	-0.06	0.09	0.10	-0.02
0819	0	0.06	0.06	0.10	0.05
1150	0.02	0.23	0.25	0.25	0.19
1360	-0.25	-0.32	-0.01	-0.11	-0.17
1457	0.05	-0.05	0.12	0.08	0.05
1814	-0.28	-0.09	-0.05	0	-0.11
1884	-0.03	0.08	0.11	0.15	0.08
2486	0.01	0.08	-0.01	0.08	0.04
5075	-0.06	-0.02	-0.04	-0.10	-0.06
5126	-0.33	-0.18	-0.09	-0.03	-0.16
5217	-0.19	-0.05	-0.06	0.06	-0.06
	General Effects of Females				
	-0.10	-0.02	0.05	0.07	

(See Beil + Atkins)

5126, and 1814 were inferior with respect to the performance of their F_1's. Martin was very superior to the other female parents in regard to the level of protein found in its test crosses (Table 6). Crosses having 0786 as a parent were the best of the male lines followed by crosses involving 5075, 1360, 1150, and 0819. It is interesting to note that hybrids of line 1150 were high in yield and had better than average percentage protein. Line 1884 was a very poor parent in regard to the protein level of its test crosses; it was also very low in protein, itself. Hybrids involving 0786 and 5075 contained protein levels which were generally higher than that of the female parents while lines 0305, 1457, 1884, and 5217 exhibited dominance for low protein in their crosses. The remaining six lines showed no dominance.

The estimates of GCA and SCA for protein yield reflect the interaction of protein level and grain yield of all the crosses (Table 7). As expected, line 1150* had the largest GCA effect of all male lines. Lines 0305, 0786, and 0819 had larger GCA effects than the average and they were about equal. Among the female lines, Redlan had the largest GCA effect which indicates the relative importance of grain yield over percentage protein in determining protein yield. The crosses of 0786 with Wheatland and Redlan yielded 8,000 kg/ha and still contained 14 or more percent protein. For percentage lysine (Table 8), females did not significantly affect it. Lines 2486, 1884, 1150, and to a lesser extent 5126, 5075, and 0819 had higher than average levels of lysine in their crosses. Estimates of GCA and SCA for lysine yield (Table 9) were somewhat similar to protein yield. Redlan was more important than the other females in influencing high lysine yield while line 1150 was the best of the males.

Table 6. Estimates of general and specific combining ability effects for percentage protein of 48 F_1 hybrids of the incomplete diallel grown in 1967.

Males	Females				General Effects of Males
	Martin	CK60	Wheatland	Redlan	
	Specific Effects				
0305	-0.02	-0.07	-0.06	-0.06	-0.05
0786	0.21	0.07	0.12	0.09	0.12
0819	0.11	-0.02	0.02	0.01	0.03
1150	0.12	-0.02	0	0.04	0.04
1360	0.19	0.03	-0.02	0.04	0.06
1457	-0.03	-0.05	-0.06	-0.06	-0.05
1814	0.05	-0.04	-0.05	-0.02	-0.01
1884	-0.10	-0.20	-0.19	-0.17	-0.16
2486	0.02	-0.05	-0.06	-0.08	-0.04
5075	0.14	0.03	0.11	0.08	0.09
5126	0.05	-0.03	-0.02	-0.03	-0.01
5217	-0.02	-0.06	0	0.04	-0.01
	General Effects of Females				
	0.06	-0.03	-0.02	-0.01	

Table 7. Estimates of general and specific combining ability effects for protein yield of 48 F_1 hybrids of the incomplete diallel grown in 1967.

Males	Females				General Effects of Males
	Martin	CK60	Wheatland	Redlan	
	Specific Effects				
0305	0.10	-0.02	0.11	0.22	0.10
0786	-0.04	0	0.23	0.21	0.10
0819	0.25	0.03	0.06	0.11	0.11
1150	0.14	0.21	0.26	0.31	0.23
1360	-0.11	-0.29	-0.03	-0.06	-0.12
1457	0.02	-0.10	0.05	0.02	0
1814	0.25	-0.13	-0.08	-0.02	-0.12
1884	-0.13	-0.13	-0.10	-0.04	-0.10
2486	0.03	0.03	-0.07	0	0
5075	0.07	0.01	0.07	-0.02	0.03
5126	-0.30	-0.21	-0.11	-0.06	-0.17
5217	-0.21	-0.11	-0.06	0.10	-0.07
	General Effects of Females				
	-0.03	-0.05	0.03	0.05	

Table 8. Estimates of general and specific combining ability effects for percentage lysine† of 48 F_1 hybrids of the incomplete diallel grown in 1967.

Males	Females				General Effects of Males
	Martin	CK60	Wheatland	Redlan	
	Specific Effects				
0305	-0.06	-0.01	-0.08	-0.08	-0.06
0786	-0.19	0.01	-0.08	-0.11	-0.09
0819	0.04	0.07	0.08	-0.13	0.02
1150	0.13	0.08	0.01	0.13	0.09
1360	-0.08	-0.11	-0.05	0	-0.06
1457	0	-0.07	-0.12	0.06	-0.03
1814	0	-0.08	-0.03	0.02	-0.02
1884	0.09	0.09	0.11	0.11	0.10
2486	0.06	0.11	0.08	0.21	0.11
5075	-0.06	0.10	-0.06	0.11	0.02
5126	0	0.03	0.02	0.16	0.06
5217	-0.06	0.02	-0.17	-0.25	-0.11
	General Effects of Females				
	-0.02	0.02	-0.02	0.02	

†Percentage lysine is proportion of lysine in the protein.

Table 9. Estimates of general and specific combining ability effects for lysine yield of 48 F_1 hybrids of the incomplete diallel grown in 1967.

Males	Females				General Effects of Males
	Martin	CK60	Wheatland	Redlan	
	Specific Effects				
0305	0.05	-0.02	0.04	0.14	0.05
0786	-0.21	0.01	0.12	0.09	0.01
0819	0.33	0.09	0.13	-0.19	0.09
1150	0.31	0.27	0.30	0.28	0.30
1360	-0.18	-0.34	-0.05	-0.06	-0.15
1457	0.06	-0.17	-0.06	0.07	-0.02
1814	-0.23	-0.19	-0.13	0	-0.14
1884	-0.02	-0.04	0.05	0.05	0.02
2486	0.09	0.16	0.03	0.19	0.12
5075	-0.01	0.13	0.02	0.10	0.06
5126	-0.29	-0.17	-0.24	0.10	-0.15
5217	-0.22	-0.07	-0.18	-0.15	-0.15
	General Effects of Females				
	-0.03	-0.03	0	.06	

Percent heterosis was calculated for each measurement of the 48 crosses and it is shown in Table 10. Heterosis is used here to designate those cases where the performance of the F_1 was superior to that of the better parent. Heterosis for grain yield was exhibited in crosses involving six of the male lines. It is particularly interesting to note that heterosis was exhibited in all four test crosses involving 0305 and that the grain yield of these test crosses were higher than other test crosses of each female parent. Only four cases of heterosis were noted for percentage protein and they involved crosses with male lines 1150 and 1360; however, they contained only moderate levels of protein. Heterosis for protein yield was found in the majority of crosses. This must have been due to an interaction of genes which governed yield and percentage protein. There was no evidence of heterosis for percentage lysine; it was usually lower in the hybrids than in the parents. Although lysine yield did exhibit heterosis in several cases, there were no crosses where heterosis had not already been shown for either grain yield or protein yield which suggested that the genes giving the heterosis response were not necessarily those controlling lysine level in the protein.

The magnitude of the correlations between characters is shown in Table 11. Grain yield and percentage protein were slightly, but significantly, negatively correlated (-0.19) while there was not a significant correlation between grain yield and percentage lysine; however, percentage protein and percentage lysine were negatively correlated (-0.34). Grain yield was highly positively correlated with protein yield (0.80) and lysine yield (0.62). Percentage protein was positively correlated with protein yield (0.14) and not with lysine yield.

Table 10. Percent heterosist of 48 F_1 hybrids for five characters measured from the incomplete diallel grown in 1967.

F_1 Hybrid	Grain Yield	% Protein	Protein Yield	% Lysine	Lysine Yield
MRT × 0305	40.2**	-15.9	41.9**	-13.0	23.7
CK60 × 0305	31.9**	- 4.8	26.0**	- 7.8	16.1
WHT × 0305	49.2**	- 9.6	43.1**	-14.5	22.8
RDL × 0305	63.0**	- 4.0	57.8**	-16.8	34.1*
MRT × 0786	25.1	- 0.6	27.5**	- 9.1	5.7
CK60 × 0786	31.7	-11.9	32.4**	- 6.0	47.4**
WHT × 0786	45.3**	- 7.9	57.7**	1.1	59.0**
RDL × 0786	39.5**	- 9.8	60.3**	-19.7	54.4**
MRT × 0819	6.4	- 4.7	23.4**	-17.9	2.1
CK60 × 0819	12.4	-11.6	1.8	-16.0	-16.3
WHT × 0819	12.7	- 7.1	4.7	-15.1	-13.4
RDL × 0819	16.7	- 8.4	9.6	-31.9	-38.0
MRT × 1150	-10.0	- 4.5	13.8*	-12.2	1.8
CK60 × 1150	7.6	11.0*	21.1**	-16.3	- 1.1
WHT × 1150	9.5	- 3.2	26.1**	-21.5	1.6
RDL × 1150	9.9	9.9*	30.3**	-12.6	- 0.4
MRT × 1360	- 0.5	2.2	20.4*	-11.8	12.6
CK60 × 1360	-10.3	9.5*	- 0.3	-16.7	- 9.8
WHT × 1360	31.2	- 5.7	24.3**	- 8.4	29.6*
RDL × 1360	12.8	9.7*	24.6**	-10.3	11.5
MRT × 1457	42.3**	-17.1	36.7**	0.2	50.9**
CK60 × 1457	28.7*	3.2	31.5**	-13.6	18.2
WHT × 1457	49.1**	- 9.1	35.5**	-12.5	34.2**
RDL × 1457	36.7**	- 0.8	36.2**	- 4.4	27.1**
MRT × 1814	12.8	-10.0	1.5	- 4.8	15.9
CK60 × 1814	27.4	- 8.2	38.9**	-13.9	18.0
WHT × 1814	26.3	- 9.5	18.4*	- 8.4	23.9
RDL × 1814	26.7	- 6.5	30.4**	- 8.3	42.7**
MRT × 1884	20.7	-23.2	17.3*	11.1	31.0*
CK60 × 1884	35.2**	- 9.7	23.5*	1.7	39.7**
WHT × 1884	37.9**	-21.3	15.7	13.1	49.0**
RDL × 1884	42.9**	-12.5	27.4**	- 0.1	49.6**
MRT × 2486	59.0**	-12.5	38.5**	- 0.6	52.0**
CK60 × 2486	52.0**	- 7.8	64.1**	3.5	61.7**
WHT × 2486	32.4*	- 9.2	19.9*	1.1	43.4**
RDL × 2486	36.7**	-10.2	33.6**	6.4	40.8**
MRT × 5075	47.3**	- 2.3	43.6**	5.5	11.5
CK60 × 5075	37.3*	- 1.3	60.0**	2.6	26.7*
WHT × 5075	27.8	6.6	37.9**	3.4	14.3
RDL × 5075	14.2	3.4	30.3**	0	23.0
MRT × 5126	5.3	-10.4	- 5.6	5.4	- 5.0
CK60 × 5126	15.2	-17.1	25.4*	3.9	11.4
WHT × 5126	21.7	-16.6	14.8	7.1	2.9
RDL × 5126	23.0	-16.9	25.6**	4.5	30.1**

Table 10. (Continued)

F_1 Hybrid	Grain Yield	% Protein	Protein Yield	% Lysine‡	Lysine Yield
MRT × 5217	11.6	-16.1	0.6	-11.0	- 7.7
CK60 × 5217	30.3	-13.0	13.3	- 4.5	10.5
WHT × 5217	26.2	- 7.9	19.9*	-20.9	- 2.6
RDL × 5217	33.4	- 4.0	40.4**	-32.1	0.2

*Significant at the .05 level.
**Significant at the .01 level.

†Heterosis refers to the hybrid being superior to the better parent.

‡Percentage lysine is a percentage of crude protein.

Table 11. Simple correlation coefficients among five characters of 65 sorghum genotypes of the incomplete diallel grown in 1967.

Characters Correlated	Correlation Coefficient†
Grain yield with percentage protein	-0.1945**
Grain yield with protein yield	0.8046**
Grain yield with percentage lysine	0.0486
Grain yield with lysine yield	0.6204**
Percentage protein with protein yield	0.1417*
Percentage protein with percentage lysine	-0.3400**
Percentage protein with lysine yield	-0.0316
Protein yield with percentage lysine	-0.0565
Protein yield with lysine yield	0.7030**
Percentage lysine with lysine yield	0.0590

*Significant at the .05 level.
**Significant at the .01 level.
†With 258 degrees of freedom values of 0.124 and 0.162 are significant at the .05 and .01 level, respectively.

Percentage lysine was not significantly related to either protein yield or lysine yield. Thus, it appears that selections could be made from these crosses that would be high in yield, percentage protein, and percentage lysine. It would be more difficult to select for high percentage protein and lysine than for high percentage protein and high grain yield in this material. Protein yield and lysine yield appeared to be determined largely by grain yield rather than by percentage protein or lysine.

Nine Parent Diallel

The F_1 seed obtained by making all possible crosses among the nine parents were chemically analyzed for percentage protein; these results are reported in Table 12. The purpose of this test was to check for differences in reciprocal crosses. In general, the F_1 which had the female parent containing the higher percentage protein was found to have a higher percentage protein than the reciprocal F_1 which had the female parent possessing a lower protein level. This difference was probably due to both dosage effects in the endosperm and effects of maternal tissue. It was also found that the crosses between parents having a low protein level were generally higher than either parent. This was probably caused by there being only a few seed (10-200) per head of the hand-crossed seed compared to several hundred on the selfed parent. Thus, all of the nitrogen that was translocated to the head appeared in a few seeds in the case of the F_1 rather than being diluted into many seeds in the parents. This could occur even without having equal amounts of nitrogen translocated in the two cases.

Table 12. Percentage protein of inbred and actual F_1 seed of diallel crosses among nine parents including reciprocals.

Male Parents	Female Parents								
	0355	0793	0819	1884	5187	MRT	CK60	WHT	RDL
0355	17.25	14.25	19.47	13.97	16.13	17.19	16.41	15.53	16.78
0793	17.59	13.66	17.44	13.50	14.84	14.69	12.47	11.50	13.59
0819	17.66	15.19	13.81	14.34	13.28	17.09	14.69	15.22	14.03
1884	16.63	13.50	16.53	9.38	14.50	15.44	12.84	14.25	13.72
5187	16.50	14.88	16.13	13.47	12.06	14.56	11.88	13.28	13.34
MRT	17.00	13.59	18.19	13.13	14.72	12.97	12.06	14.66	12.91
CK60	16.59	14.78	20.16	13.16	13.63	14.56	11.00	14.91	13.16
WHT	16.34	14.09	17.34	13.53	16.09	15.31	12.78	13.34	13.06
RDL	16.88	14.75	15.38	13.00	13.81	15.63	11.94	16.66	10.31

Results of the analysis of the diallel experiment grown in 1968 (Table 13) showed a highly significant variation among genotypes for each of the 13 characters. Many of the characters, such as percentage protein, leaf number, 100 seed weight, and height, had low C.V.'s. None of the C.V.'s were large enough to cause concern. It was interesting to note that the technique used to measure percentage lysine had improved in this portion of the study compared to the earlier part; the C.V. in the first part was 16.03 percent while it was 10.05 percent in this part of the study. The range of mean values for each character was as follows: From 6 to 45 days after July 1 for flowering, 10.3 to 19.0 leaves for leaf number, 108 to 414 cm for height, 96 to 215 cm^2 for flag leaf area index, 10.4 to 29.1 cm for head exertion, 13.4 to 35.7 cm for head length, 3143 to 15,863 kg/ha for grain yield, 15.9 to 99.7 grams for yield per head, 9.18 to 18.22 percent for percentage protein, 546 to 1841 kg/ha for protein yield, 1.74 to 2.74 percent for percentage lysine, and 5.15 to 18.07 kg/ha for lysine yield. The genotypic means for the six characters concerned with vegetative growth are reported in Appendix Table 2 and the means for characters determined from the grain are shown in Appendix Table 3.

From the combining ability analysis of variance for each of the 13 characters (Table 14) highly significant GCA and SCA components of variance were found for each. The interpretation of this was that both additive and non-additive genes were involved in the control of the expression of each character. In all cases GCA mean squares were found to be larger than SCA; however, the ratios of the two were rather low (less than 10:1) for flag leaf area index, head exertion, yield per head, grain yield, protein yield, and percentage lysine. The GCA:SCA

Table 13. Analyses of variance for 13 characters measured from the sorghum diallel of nine parents and 36 F_1 hybrids grown in 1968.

Character	Mean Squares†			CV(%)
	Blocks	Entries	Error	
Flowering	28.32 **	306.02 **	4.61	11.68
Leaf Number	1.60	20.87 **	0.68	6.15
Height	676.50	35901.26 **	274.62	7.03
L.A.I.	1758.44 **	3416.58 **	787.26	17.88
Head Exert.	6.34	77.41 **	11.10	17.08
Head Length	13.65	84.48 **	5.38	9.13
Grain Yield	526210 *	5689984 **	185712	12.28
Yield/Head	263.88 **	1054.35 **	35.81	14.05
100 Seed Wt.	0.1758**	1.8287**	0.0321	6.47
% Protein	0.3772	22.5586**	0.3789	4.95
Protein Yield	3774	56136 **	2650	12.27
% Lysine	0.0720	0.1278**	0.0441	10.05
Lysine Yield	0.93	30.25 **	1.64	14.57

*Significant at the .05 level.
**Significant at the .01 level.
†The mean squares for blocks, entries, and error have 3, 44, and 132 degrees of freedom, respectively.

Table 14. Combining ability analyses of variance and heritability estimates for 13 characters measured from the sorghum diallel of nine parents and 36 F_1 hybrids grown in 1968.

Character	Mean Squares†			GCA:SCA ratio	H†† (%)
	GCA	SCA	Error		
Flowering	349.84 **	15.76 **	1.15	22:1	40
Leaf Number	24.43 **	0.95 **	0.17	26:1	39
Height	39006 **	2302 **	69	17:1	39
L.A.I.	2739 **	420 **	197	7:1	16
Head Exertion	52.86 **	11.17 **	2.77	5:1	17
Head Length	95.47 **	4.14 **	1.34	23:1	34
Grain Yield	5428697 **	531638 **	46428	10:1	52
Yield Per Head	892.55 **	123.80 **	8.95	7:1	0
100 Seed Weight	2.0187**	0.0893**	0.0080	23:1	38
% Protein	27.0374**	0.8846**	0.0947	31:1	42
Protein Yield	50166 **	6005 **	663	8:1	28
% Lysine	0.1763**	0.0274**	0.0110	6:1	2
Lysine Yield	31.0005**	2.3542**	0.4102	13:1	32

**Significant at the .01 level.
†The mean squares of GCA, SCA, and error have 8, 36, and 132 degrees of freedom, respectively.
††Heritability estimated in the narrow sense.

ratios for flowering, leaf number, head length, 100 seed weight, and especially percentage protein were quite high (20:1 or greater) indicating the relative importance of additive gene action in controlling their expression. Thus, it appears that the desirable characteristics exhibited in crosses between the nine parents could be incorporated into inbred lines. If SCA (the non-additive gene action) had been more important than GCA for any character, it would be necessary to develop hybrids in order to utilize the non-additive gene action.

The magnitude of the additive gene action was confirmed by the estimates of narrow sense heritability which are reported in Table 14. The highest estimate of heritability was for grain yield where about 50 percent of the total variation was due to additive gene action. Additive gene action accounted for approximately 40 percent of the total variation for the other characters except for flag leaf area index, head exertion, yield per head, and percentage lysine which had very low heritability estimates.

Estimates of GCA effects of the nine parents for 13 characters are reported in Table 15. Line 0355 and, to a lesser extent, 0819 and 1884, had the largest effects on late flowering in the crosses. Crosses involving Martin and Combine Kafir 60 tended to be earlier. Lines 0819, 0355, and 1884 had the greater effects on increasing leaf number. Line 0355 followed by 0819 and 0793 had the greatest effect on increasing height while line 5187 and Wheatland were most important in reducing height. The flag leaf area index was influenced the most in a positive direction by line 0793, 0355, Wheatland and Martin. Line 0355 and Martin had the greatest effect on increasing head exertion and, along with line 1884, head length. Grain yield was increased by lines 0793,

Table 15. Estimates of general combining ability effects of nine parents for 13 characters measured from the nine parent sorghum diallel grown in 1968.

Character	Parents									
	0355	0793	0819	1884	5187	MRT	CK60	WHT	RDL	S.E.*
Flowering	11.23	- 3.38	4.61	4.70	- 2.41	- 5.22	- 5.57	- 1.13	- 2.84	0.46
Leaf Number	1.58	0.76	2.19	1.49	- 1.26	- 1.49	- 1.44	- 0.66	- 1.17	0.18
Height	115.22	25.10	67.92	6.81	- 60.24	- 35.58	- 37.40	- 49.90	-31.04	3.53
L.A.I.	16.03	22.89	- 13.91	- 16.59	- 0.94	8.24	- 13.10	14.48	-17.10	5.98
Head Exert	3.36	- 1.08	- 2.70	0.66	- 2.28	3.48	- 0.87	- 0.34	- 0.23	0.71
Head Length	4.65	- 3.00	- 4.88	3.88	- 0.88	1.18	- 0.57	0.65	- 0.57	0.49
Grain Yield	-1360	881	856	583	-335	-272	-174	-179	1	91.9
Yield/head	- 16.06	10.63	13.77	5.79	- 4.36	- 5.19	- 2.65	- 1.30	- 0.63	1.28
100 seed wt.	- 0.86	0.68	0.48	- 0.02	0.01	- 0.14	- 0.08	- 0.05	- 0.02	0.04
% Protein	3.88	- 0.28	0.26	- 1.53	- 0.46	0.40	- 0.81	- 0.80	- 0.66	0.13
Protein yield	- 77	100	120	16	- 46	- 15	- 39	- 42	-16	11.0
% Lysine	- 0.21	- 0.04	0.11	0.24	- 0.01	- 0.08	0.06	- 0.02	- 0.05	0.04
Lysine yield	- 2.38	1.88	2.97	1.25	- 1.01	- 0.65	- 0.63	- 0.95	- 0.49	0.27

*Standard error of the difference between two effects.

0819, and 1884 and it was decreased by line 0355; these four lines were probably the most diverse in this study. Yield per head, protein yield, and lysine yield were affected by the parents in an almost identical manner as grain yield which was not surprising because of the nature by which they were calculated. Lines 0793 and 0819 had the greatest influence on increasing 100 seed weight while line 0355 had the greatest effect of reducing 100 seed weight. Percentage protein was increased primarily by line 0355 and secondarily by line 0819 and Martin; line 1884 had the greatest effect of reducing percentage protein. Lines 1884 and 0819 had the largest effects for high percentage lysine while line 0355 was the most important in reducing lysine level in the protein.

Estimates of SCA effects from the 36 F_1 hybrids for the six vegetative characters are shown in Table 16 and the estimates for the seven characters concerning characteristics of the grain are reported in Table 17. The cross of 0355 × 1884 had the largest effect on late flowering. Crosses involving 0355 generally had the largest SCA effects for late flowering while 0793 crosses generally appeared to have large SCA effects for early flowering. The cross of 0355 × 1884 also had the largest SCA effect for leaf number indicating a possible relationship of late flowering with greater leaf number which was confirmed by looking at the relationships in other crosses. High estimates of SCA effects for height were found in crosses 0355 × 5187 and 0819 × 1884. The largest SCA effect for flag leaf area index was from the cross of 0793 × 0819. Crosses of 5187 with 0355 and 0793 had large SCA effects for head exertion. Large SCA effects for head length were manifested in crosses of 1884 × Redlan, 1884 × Combine Kafir 60, 0355 ×

Table 16. Estimates of specific combining ability effects of 36 F_1 hybrids for 6 characters measured from the nine parent sorghum diallel grown in 1968.

Hybrid	Flowering	Leaf No.	Height	L.A.I.	Head Exert.	Head Length
0355 × 0793	3.03	0.93	-13.6	9.3	-3.78	0.52
0355 × 0819	- 5.97	-1.33	-43.9	6.8	1.04	-0.21
0355 × 1884	10.44	2.55	56.0	-40.3	-1.05	2.32
0355 × 5187	2.55	1.45	73.0	3.6	7.00	-3.88
0355 × MRT	3.37	-0.25	19.6	34.0	-2.16	3.21
0355 × CK60	4.96	1.05	53.9	30.1	0.49	-0.52
0355 × WHT	0.53	0.70	43.9	-10.9	2.23	-0.06
0355 × RDL	1.24	0.06	48.5	-36.3	3.33	-1.45
0793 × 0819	4.15	0.85	-36.3	49.3	-5.28	3.10
0793 × 1884	- 1.70	-0.83	8.6	17.9	-0.38	0.01
0793 × 5187	- 4.33	-0.62	39.4	- 6.8	7.62	-3.10
0793 × MRT	- 3.76	-0.40	29.7	-26.7	3.29	-0.26
0793 × CK60	- 2.17	-1.05	29.0	-14.2	1.36	0.29
0793 × WHT	- 3.60	0.23	50.3	- 4.8	4.50	0.05
0793 × RDL	- 1.90	-0.17	37.3	- 4.5	2.97	-0.04
0819 × 1884	1.55	0.76	68.3	8.2	3.99	-0.87
0819 × 5187	- 0.33	0.49	49.1	13.5	-0.79	1.91
0819 × MRT	0.24	0.84	40.6	- 2.6	0.56	-0.01
0819 × CK60	- 1.67	0.29	25.0	-30.4	1.88	1.34
0819 × WHT	5.15	0.82	50.0	-25.6	3.27	-1.30
0819 × RDL	- 0.40	0.70	49.5	3.3	-0.18	0.32
1884 × 5187	- 1.67	-0.38	-12.3	9.7	-6.15	1.68
1884 × MRT	- 5.85	-0.93	3.0	25.4	3.27	0.59
1884 × CK60	- 4.76	-0.84	- 1.4	1.4	-2.54	3.17
1884 × WHT	1.80	-0.39	- 2.7	12.7	-1.55	0.48
1884 × RDL	- 1.24	-0.61	1.9	21.8	0.80	4.12
5187 × MRT	2.01	-0.15	-13.7	- 6.1	-0.41	0.19
5187 × CK60	1.35	-0.08	-26.9	13.5	-1.67	1.69
5187 × WHT	- 0.58	-0.73	-18.1	3.8	0.60	1.25
5187 × RDL	1.62	-0.23	-24.8	- 6.9	-1.33	0.19
MRT × CK60	0.67	0.47	18.5	- 0.8	0.78	-2.70
MRT × WHT	- 0.26	0.07	-24.0	15.0	-2.46	0.94
MRT × RDL	- 1.06	-0.15	-24.5	6.5	-0.51	-0.37
CK60 × WHT	- 4.67	-1.01	-24.7	14.7	2.81	-0.16
CK60 × RDL	0.28	-0.18	-23.9	- 1.4	0.09	-1.27
WHT × RDL	- 3.15	-0.43	-20.2	16.7	-2.15	-2.04
$S.E._a$*	1.21	0.55	11.2	18.9	2.25	1.56
$S.E._b$†	1.45	0.53	10.6	17.9	2.13	1.48

*Standard error of the difference between effects of two crosses having one parent line in common.

†Standard error of the difference between effects of two crosses having no parent in common.

Table 17. Estimates of specific combining ability effects of 36 F_1 hybrids for seven characters measured from the nine parent sorghum diallel grown in 1968.

Hybrid	Grain Yield	Head Yield	100 Seed Wt.	% Protein	Protein Yield	% Lysine	Lysine Yield
0355 × 0793	-1054	-15.3	-0.44	0.16	-121.4	0.056	-2.22
0355 × 0819	- 717	-15.2	-0.16	-0.51	- 94.8	-0.113	-2.48
0355 × 1884	- 481	- 5.9	-0.35	1.64	10.8	-0.197	-0.56
0355 × 5187	512	2.5	-0.60	0.41	82.1	-0.062	1.45
0355 × MRT	88	4.5	0.19	1.51	31.0	-0.055	0.45
0355 × CK60	399	13.7	0.06	0.72	81.0	-0.157	1.03
0355 × WHT	- 149	- 0.8	0.21	1.18	3.5	-0.125	-0.19
0355 × RDL	54	5.5	0.26	0.59	31.4	-0.094	0.29
0793 × 0819	2132	32.7	-0.29	-0.80	217.1	-0.053	4.43
0793 × 1884	129	0.1	0.04	0.13	12.3	-0.109	0.01
0793 × 5187	589	2.2	0.39	-0.48	47.0	-0.069	0.67
0793 × MRT	93	- 0.4	0.23	-0.63	- 1.8	0.123	0.41
0793 × CK60	265	- 1.7	0.25	-0.57	3.0	-0.092	-0.33
0793 × WHT	143	3.8	0.22	-0.91	- 20.9	0.268	0.82
0793 × RDL	342	6.4	0.44	-0.05	38.9	0.157	1.54
0819 × 1884	1051	13.0	0.23	0.81	161.6	-0.276	2.47
0819 × 5187	645	15.4	0.32	-0.37	61.7	-0.049	1.21
0819 × MRT	400	7.3	0.06	-0.30	45.2	0.101	1.47
0819 × CK60	125	- 0.4	0.25	0.06	15.7	0.001	0.36
0819 × WHT	210	4.9	0.31	0.42	43.5	-0.244	-0.33
0819 × RDL	339	6.0	0.21	-0.24	31.1	-0.038	0.43
1884 × 5187	- 25	5.5	-0.13	-1.12	- 41.2	0.145	-0.42
1884 × MRT	9	- 3.5	0.19	-1.00	- 26.2	-0.178	-1.27
1884 × CK60	283	21.1	0.31	-0.59	2.1	0.170	0.74
1884 × WHT	555	12.7	0.17	-0.31	44.4	0.010	1.06
1884 × RDL	730	8.8	0.17	-1.07	23.1	0.091	0.86
5187 × MRT	- 194	- 3.5	0.35	1.15	6.5	-0.001	0.11
5187 × CK60	- 530	- 2.6	-0.15	0.68	- 45.0	-0.165	-1.43
5187 × WHT	- 79	- 0.4	0.06	0.14	- 0.6	0.030	0.05
5187 × RDL	- 314	- 7.1	0.28	1.25	3.2	-0.056	0.16
MRT × CK60	299	4.1	-0.03	-0.37	27.0	0.064	0.84
MRT × WHT	- 291	- 3.6	-0.18	0.16	- 24.5	-0.056	-0.78
MRT × RDL	- 290	- 3.7	-0.37	0.29	- 22.3	0.025	-0.45
CK60 × WHT	- 302	- 5.2	-0.26	0.57	- 12.0	-0.181	-0.88
CK60 × RDL	- 174	- 2.1	-0.08	0.21	- 8.9	-0.144	-0.71
WHT × RDL	- 330	- 6.7	-0.36	-0.41	- 44.3	-0.112	-0.98
$S.E._a$*	290	4.0	0.12	0.42	34.7	0.142	0.86
$S.E._b$†	276	3.8	0.11	0.39	32.9	0.134	0.82

*Standard error of the difference between effects of two crosses having one parent line in common.

†Standard error of the difference between effects of two crosses having no parent in common.

1884, and 0793 × 0819. The better combiners for grain yield also had the large SCA effects; these crosses were 0793 × 0819 and 0819 × 1884. The cross of 0793 × 0355 had the lowest SCA effect. Head yield, protein yield, and lysine yield followed the same pattern as grain yield. Large SCA effects for 100 seed weight were found in crosses of 0793 with Redlan and 5187. The crosses of 0355 × 0793 and 0355 × Martin had large SCA effects for percentage protein; this was especially interesting because the three parents involved in the two crosses were three of the four parents which had the high protein levels.

The values of percent heterosis for the vegetative characters are noted in Table 18 and the values for grain characters are reported in Table 19. Heterosis for flowering was calculated to show that the F_1 hybrid was earlier than either parent. The crosses of 0793 with 5187, Martin, Combine Kafir 60, Wheatland, and Redlan were earlier than either parent. Heterosis for leaf number was only exhibited in crosses of 0355 with 0819, 1884, and 5187. Several crosses showed heterosis for height, especially those involving 0793 and 0819; however, the cross of 0793 × 0819 was no taller than either parent. No heterosis was noted for the flag leaf area index and only a few cases were noted for head exertion and head length. Several instances of heterosis for grain yield were found; these usually involved crosses of 0793, 0819, and 1884. Again, these three parents were quite diverse in type from the others. The same parents were responsible for heterosis of yield per head. Four crosses exhibited heterosis for percentage protein and probably the most significant cross in terms of protein level was that of 0355 × Martin; these parents had the highest and a relative high level of protein, respectively. Several crosses which usually had 0819

Table 10. Percent heterosis of the F_1 hybrids for six characters measured from the nine parent sorghum diallel grown in 1968.

F_1 Hybrid	Flowering	Leaf No.	Height	L.A.I.	Head Exertion	Head Length
0355 × 0793	-42.7	7.9*	4.3	6.3	-21.7	-20.8
0355 × 0819	- 7.1	- 1.4	7.9*	-13.1	- 7.1	-28.3
0355 × 1884	-36.3	13.8**	19.1**	-39.3	- 4.1	3.0
0355 × 5187	-55.5	8.6*	4.7	- 7.9	21.6*	-27.7
0355 × MRT	-63.1	- 5.2	- 3.6	12.6	- 4.0	- 0.9
0355 × CK60	-64.7	4.5	5.8	- 0.5	- 0.9	-16.7
0355 × WHT	-36.2	7.5	- 0.7	- 7.3	9.1	-11.8
0355 × RDL	-46.4	- 0.7	5.8	-37.2	14.3	-19.4
0793 × 0819	-29.5	7.0	8.1	11.4	-13.3	7.8
0793 × 1884	- 6.9	- 7.8	29.2**	- 6.2	-20.1	- 2.5
0793 × 5187	60.6**	-20.6	12.3*	-10.9	89.9**	-23.1
0793 × MRT	70.8**	-20.6	19.3**	-16.1	0	-13.4
0793 × CK60	41.3*	-24.5	18.1**	-20.7	18.0	- 4.2
0793 × WHT	63.4**	-11.2	22.2**	- 1.6	50.3*	-14.8
0793 × RDL	46.3**	-17.1	24.6**	-18.1	14.8	-11.3
0819 × 1884	-10.3	6.7	40.0**	14.4	- 8.5	-13.1
0819 × 5187	-34.6	- 7.8	8.1	9.1	9.6	- 8.9
0819 × MRT	-43.1	- 7.0	14.1**	- 1.3	-17.6	-19.6
0819 × CK60	-34.9	-10.1	7.7	-19.4	11.1	- 8.2
0819 × WHT	-31.5	- 2.0	12.3**	-24.6	31.3*	-27.0
0819 × RDL	-24.9	- 5.1	18.8**	4.9	-10.7	-19.0
1884 × 5187	-30.3	-20.8	- 9.9	4.2	-50.0	11.7
1884 × MRT	-14.6	-25.4	11.3	15.2	7.5	13.6*
1884 × CK60	-19.4	-24.5	7.9	4.0	-28.6	18.8**
1884 × WHT	-22.1	-17.2	1.7	- 4.0	-23.1	10.4
1884 × RDL	-21.1	-21.6	12.6*	18.9	-17.8	21.7**

Table 18. (Continued)

F_1 Hybrid	Flowering	Leaf No.	Height	L.A.I.	Head Exertion	Head Length
5187 × MRT	-19.4	- 4.6	- 9.2	4.6	-19.8	- 3.9
5187 × CK60	-12.7	- 4.1	-28.3	9.8	- 8.4	8.5
5187 × WHT	- 7.0	-13.7	- 1.1	- 0.6	16.3	- 3.3
5187 × RDL	-10.2	- 7.1	-20.8	- 7.7	-14.6	- 0.6
MRT × CK60	24.2	- 2.2	29.5**	0	- 8.6	-13.4
MRT × WHT	-12.7	- 9.1	- 9.8	11.4	-19.4	3.7
MRT × RDL	10.8	- 8.4	- 4.2	2.6	-11.2	- 7.7
CK60 × WHT	46.4*	-17.3	- 9.2	- 1.1	31.8*	- 6.7
CK60 × RDL	0	- 8.2	- 5.0	1.6	0.8	- 6.4
WHT × RDL	33.3*	-10.5	-10.2	- 2.3	- 8.5	-13.7

*Significant at the .05 level.
**Significant at the .01 level.

†Heterosis = percent above better parent.

Table 19. Percent heterosis† of the F_1 hybrids for seven characters measured from the nine parent sorghum diallel grown in 1968.

F_1 Hybrid	Yield Per Head	100 Seed Wt.	% Protein	Protein Yield	% Lysine††	Lysine Yield	Grain Yield
0355 × 0793	-56.3	-41.8	- 6.4	-39.7	- 7.1	-38.4	-50.0
0355 × 0819	-34.2	-31.9	- 7.3	-12.2	-29.0	-37.3	-26.9
0355 × 1884	-29.9	-36.9	- 5.4	3.1	-29.9	-27.6	-36.6
0355 × 5187	-11.2	-17.7	- 6.2	40.2**	-17.5	16.8	- 8.4
0355 × MRT	-18.6	-13.8	5.0*	- 3.6	-14.8	-13.5	-32.4
0355 × CK60	12.9	-22.7	- 6.5	24.0*	-27.5	- 1.8	-20.3
0355 × WHT	-35.3	-18.8	- 3.7	-10.8	-21.4	-29.6	-44.3
0355 × RDL	-17.1	-12.8	- 6.3	- 1.9	-15.1	-14.1	-33.9
0793 × 0819	99.4**	- 1.6	-13.4	60.9**	-20.5	66.0**	86.7**
0793 × 1884	18.0*	- 5.2	-20.1	3.0	-20.4	21.3*	29.1**
0793 × 5187	1.6	3.9	-16.5	- 2.3	-10.0	4.3	17.5*
0793 × MRT	- 4.8	- 4.3	-11.5	- 6.6	9.4	5.4	6.6
0793 × CK60	- 2.2	- 2.4	-19.1	- 9.2	-17.8	- 2.0	13.4
0793 × WHT	10.8	- 2.4	-22.3	-14.3	4.2	6.6	10.2
0793 × RDL	17.4*	4.6	-14.9	1.9	6.7	18.4*	19.8*
0819 × 1884	96.9**	6.1	-10.4	71.9**	-21.2	41.3**	69.1**
0819 × 5187	76.6**	9.5*	-11.4	32.5**	-19.6	9.1	49.5**
0819 × MRT	53.1**	- 2.8	- 4.5	35.9**	-17.1	14.9	43.6**
0819 × CK60	39.6**	4.6	- 9.8	23.2*	-14.6	4.9	38.0**
0819 × WHT	57.1**	7.3	- 8.0	29.1**	-26.5	- 3.3	34.4**
0819 × RDL	61.6**	6.2	-11.9	32.4**	-10.1	6.9	41.1**
1884 × 5187	31.2**	8.0	-12.9	- 2.9	- 9.7	-12.3	5.2
1884 × MRT	5.2	15.4	19.5	6.1	-24.5	-17.1	7.9
1884 × CK60	26.8*	22.3	- 9.1	11.2	- 6.8	3.2	18.4*
1884 × WHT	15.8*	11.2	- 6.0	22.1*	-16.1	3.2	25.9**
1884 × RDL	49.8**	18.1	-15.2	22.6*	-14.5	5.8	35.9**

Table 19. (Continued)

F_1 Hybrid	Yield Per Head	100 Seed Wt.	% Protein	Protein Yield	% Lysine††	Lysine Yield	Grain Yield
5187 × MRT	- 7.7	32.3	6.5	- 3.4	- 8.9	1.9	- 6.9
5187 × CK60	- 1.1	4.5	11.7*	- 6.8	-19.2	-26.0	-17.0
5187 × WHT	- 3.0	8.1	5.8	- 2.6	- 5.0	- 8.3	-10.9
5187 × RDL	-19.2	23.3	16.2**	- 0.3	-10.0	- 2.8	-14.2
MRT × CK60	16.7	3.7	- 9.0	5.4	-13.3	8.1	12.9
MRT × WHT	-14.7	- 6.0	- 4.7	- 9.3	-12.7	-14.7	-15.4
MRT × RDL	-12.4	- 8.3	- 2.5	- 1.6	- 2.1	- 0.5	-11.6
CK60 × WHT	-11.3	- 7.9	10.1*	- 4.1	-20.4	-17.7	-12.7
CK60 × RDL	- 1.4	5.5	3.3	- 1.7	-20.4	- 9.4	- 5.2
WHT × RDL	-10.1	- 9.4	- 2.1	-12.2	-10.0	-14.7	- 9.0

*Significant at the .05 level.
**Significant at the .01 level.

†Heterosis = percent above better parent

††Percentage lysine is the proportion of lysine in the protein.

as one parent were superior to either parent for protein yield. Only a few crosses showed heterosis for lysine yield and they involved crosses of 0819 and 1884 with the exception of one cross.

Simple correlation coefficients were calculated to indicate the magnitude of relationships among the 13 characters (Table 20). Percentage protein was positively associated with flowering, height, flag leaf area index, head exertion, and head length; it was negatively correlated with grain yield, yield per head, 100 seed weight, protein yield, percentage lysine, and lysine yield. Percentage lysine was positively related to grain yield, yield per head, 100 seed weight, and lysine yield, and it was negatively associated with height, flag leaf area index, head exertion, and percentage protein. Thus, it acted almost exactly opposite of percentage protein. Grain yield was positively correlated with leaf number, yield per head, 100 seed weight, protein yield, percentage lysine, and lysine yield and it was negatively related to flowering, head exertion, head length, and percentage protein. These correlation coefficients only indicate the overall relationships and do not necessarily show the actual relationship for the most outstanding crosses. In order to determine the characteristics of the highest combiners for yield, percentage protein, and percentage lysine, the genotypic means in Appendix Table 2 and Appendix Table 3 were examined. Then the highest yielding crosses usually flowered late, had heavier seeds and more than average number of leaves, tended to be taller than average, varied a lot for head exertion and length, contained moderate to low levels of protein and high levels of lysine. The six highest yielding hybrids involved crosses among 0793, 0819, 1884, and Redlan. Those lines and crosses having the highest levels of protein were

Table 20. Simple correlation coefficients among 13 characters measured from the diallel of nine parents grown in 1968.†

Character	Leaf Number	Height	L.A.I.	Head Exertion	Head Length	Grain Yield	Yield Per Head	100 Seed Weight	% Protein	Protein Yield	% Lysine	Lysine Yield
Flowering	.79**	.70**	-.30**	.10	.32*	-.20*	-.09	-.39**	.61**	.03	-.11	-.01
Leaf Number		.77**	-.02*	-.01	-.01	.21**	.29**	.04	.34**	.40**	.05	.39**
Height			.08	.29**	.11	.05	.14	-.07	.62**	.33**	-.21**	.23**
L.A.I.				.01	.18*	-.04	-.03	.08	.22**	.05	-.24**	-.05
Head Exertion					.40**	-.24**	-.29**	-.28**	.33**	-.14	-.28**	-.23**
Head Length						-.40**	-.36**	-.63**	.28**	-.41**	-.14	-.42**
Grain Yield							.93**	.77**	-.57**	.90**	.27**	.91**
Yield/head								.73**	-.48**	.86**	.22**	.86**
100 seed wt.									-.52**	.69**	.23**	.70**
% Protein										-.18*	-.51**	-.35**
Protein yield											.05	.92**
% Lysine												.43**

*Significant at the .05 level.
**Significant at the .01 level.
†With 178 degrees of freedom, values of 0.154 and 0.206 are significant at the .05 and .01 level, respectively.

generally found to be later, to have longer heads, lighter seed, greater than average number of leaves, to be tall, to exert their heads further than average, and to contain low levels of lysine. The nine entries with the highest protein levels had 0355 as one parent. However, lines and crosses which contained moderate levels of protein (12 to 14 percent) were variable for the other characters. In fact, the highest amounts of protein and lysine yield were found in this group. Lines 0793, 0819, and Martin were parents of hybrids falling in this group. Thus, it appears that selections could be obtained from this material which would be better than average for percentage protein and high in grain yield and percentage lysine.

The variance-covariance analysis was examined for each character. The analysis of variance of the Wr minus Vr values indicated significant effects of blocks and arrays for several characters (Appendix Table 4). The Wr,Vr regression coefficients for grain yield and head exertion deviated significantly from unity which indicated that the assumptions of the Jinks-Hayman analysis were not met for these two characters as well as for the characters for which significant effects of blocks and arrays were found. Since the validity of conclusions derived from the Wr,Vr analysis was uncertain when the assumptions were not satisfied, no Wr,Vr graphs are shown.

Summary and Conclusions

Four by Twelve Parent Incomplete Diallel

Twelve diverse lines from the world collection of sorghum were evaluated for their combining ability for grain yield, percentage protein, percentage lysine, protein yield, and lysine yield. The twelve lines

were crossed onto four male sterile lines and the performance of the F_1 hybrids was used to estimate GCA, SCA, and percent heterosis. Mean squares of genotypes for all characters were significant in the analysis of variance. Grain yield ranged from 3088 to 9286 kg/ha; percentage protein varied from 10.23 to 15.53 percent; percentage lysine ranged from 1.25 to 1.97 percent of the protein; protein yield was between 573.9 and 1192.5 kg/ha; and lysine yield ranged from 7.66 to 18.58 kg/ha.

Combining ability analysis of variance indicated a significant GCA of both male and female effects for grain yield, percentage protein, and protein yield and only the male effect of GCA was significant for percentage lysine and lysine yield. The SCA mean squares which were estimated by the male by female interaction were not significant. These results suggest that the characters were controlled primarily by additive gene action. Wheatland and Redlan had greater effects of the females on increasing yield in the hybrids while 0355 and 1150 were more important male lines in this regard. Martin and 0786 had the biggest effects on percentage protein of the females and males, respectively. For percentage lysine 2486 and 1884 had the larger GCA effects.

Several crosses exhibited heterosis for grain yield, protein yield, and lysine yield. Only four crosses showed heterosis for percentage protein and there were no cases of significant heterosis for percentage lysine. Grain yield was slightly negatively correlated (-0.19) with percentage protein and not significantly related to percentage lysine. However, percentage protein was negatively associated (-0.34) with percentage lysine.

The overall results suggest that selections can be made from these crosses for high grain yield and high percentage protein. High

percentage lysine can be incorporated into high percentage protein but selection for both would be more difficult than selecting for either high grain yield and high percentage protein or high grain yield and high percentage lysine.. Since the genetic variability exhibited in this experiment was primarily due to additive and simple dominant gene action, it should be possible to combine many favorable genes into homozygous lines. This should have a lot of potential for those areas of the world lacking a hybrid seed industry.

Nine Parent Diallel

Nine parents were selected for a range of 9 to 18 percent protein and 1.87 to 2.74 percent lysine in the protein. They also were selected for a wide variation in several morphological characters. Gene action for grain yield, percentage protein, percentage lysine, and 10 other characters were analyzed from the performance of the parents and the diallel set of F_1 hybrids.

Reciprocal differences were found in the protein level of F_1 seed obtained by making all possible crosses among the nine parents. The differences appeared to be due to maternal effects and dosage effects in the endosperm. A wide range in each character was found in the 45 genotypes which were grown in this study. The ranges were as follows: 6 to 45 days after July 1 for flowering, 10.3 to 19.0 leaves, 108 to 414 cm for height, 96 to 215 cm^2 for flag leaf area index, 10.4 to 29.1 cm for head exertion, 13.4 to 35.7 cm for head length, grain yield was 3143 to 15863 kg/ha, 15.9 to 99.7 grams for yield per head, 1.20 to 3.88 grams for 100 seed weight, 9.18 to 18.22 percent protein, 1.74 to 2.74 percent lysine, 546 to 1841 kg/ha for protein yield, and 5.15 to 18.07 kg/ha for lysine yield.

Combining ability analysis for the 13 characters measured in this experiment from the F_1 plants disclosed highly significant GCA and SCA variation for each character. The GCA:SCA mean square ratio indicated that additive gene action had a greater effect on genetic variability than did non-additive gene action. High ratios of 20:1 or greater were calculated for flowering, leaf number, height, head length, 100 seed weight, and percentage protein while lower ratios of 10:1 or less were found for flag leaf area index, head exertion, grain yield, yield per head, protein yield, percentage lysine, and lysine yield. Estimates of GCA effects showed 0355 to influence late flowering while Martin and Combine Kafir 60 promote early flowering. Greater leaf number was found in crosses involving 0355, 0819, and 1884. Line 0355 had the greatest effect of stimulating height while 5187 was the most important in reducing height. Martin and 0355 had the greatest GCA effects on head exertion and head length. Lines 0793, 0819, and 1884 had the largest effects on grain yield, yield per head, protein yield, and lysine yield; 0355 had the biggest negative effect on these characters. Line 0355 had the largest GCA effect on percentage protein while 1884 had the biggest effect in the negative direction. The largest GCA effect for percentage lysine came from 1884. Line 0819 had the second largest GCA effect for both percentage protein and lysine. Several important SCA effects were noted. The most important of these were found in crosses 0793 × 0819 and 0819 × 1884 which yielded the highest and second highest, respectively. Another cross, 0355 × Martin, had the highest percentage protein which was remarkable in the fact that 0355 had the highest level of protein of the nine parents and Martin was among the four high parents in percentage protein. The performances of these

crosses reflect the importance of genetic diversity in producing superior genotypes. Heterosis was noted in several crosses for every character except for flag leaf area index and percentage lysine.

Grain yield was found to be positively correlated with percentage lysine, lysine yield, protein yield, 100 seed weight, yield per head, and leaf number and it was negatively correlated with percentage protein, late flowering, head exertion, and head length. Percentage lysine had similar associations with other characters as did grain yield. Percentage protein was positively related to flowering, leaf number, height, flag leaf area index, head exertion, and head length; it was negatively correlated with grain yield, percentage lysine, protein yield, lysine yield, yield per head, and 100 seed weight.

The results of this experiment suggest that the 13 characters were primarily under the control of additive gene action. However, non-addtive gene action was also important; part of it was caused by partially dominant genes (fully dominant in the case of percentage lysine) and the remainder by gene interactions. The magnitude of the addtive gene action indicates that superior homozygous lines can be developed from these crosses. However, the full utilization of the genetic variability exhibited in the crosses depends on the use of hybrids because there was a significant proportion of the genetic variability due to non-additive gene action. It should be possible to obtain high yields with significantly better than average levels of protein and lysine.

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SECTION II

INHERITANCE OF PERCENTAGE PROTEIN AND ITS RELATIONSHIP TO OTHER CHARACTERS IN *SORGHUM BICOLOR* (L.) MOENCH

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Introduction

The results of previous research at Purdue University have identified several high protein lines from the world collection of sorghum. The F_1 hybrids of crosses between some of these high protein lines have exhibited high yields with better than average protein levels. Five sets of crosses among three of the high protein lines and a low protein line were examined for percentage protein and its association to eight other characters. This study was designed to give preliminary evidence about gene number and type of gene action which control the protein level in the grain of these five crosses as well as the association of percentage protein with other characters. Another objective in this experiment was to determine whether the protein levels in the three high protein lines were controlled by the same gene(s).

Review of Literature

No published reports were found on the inheritance of percentage protein in the grain of sorghum which were based on the individual plant performance of parents, F_1's and F_2's. However, there have been several investigations reported which described the inheritance of other agronomic characteristics. Three of the most recent were by Beil and Atkins (1), Voigt *et al.* (24), and Liang and Walter (17) in which they had examined populations of parents, F_1's, F_2's, and backcrosses.

While little has been done to improve the protein level in sorghum in the past, there has been a lot of interest and effort given to increasing the protein level in corn and wheat. Hayes (12) and Hayes and Garber (13) reported that dominance for low protein content existed in the crosses which they studied. They also found a negative correlation between the number of seeds produced per ear and protein percentage and they found little, if any, effect of foreign pollen on the protein level the year the cross was made. Frey (7, 8) also reported dominance for low protein percentage but he suggested that the lower percentage protein in crossed seeds was due to heterotic dilution; a negative correlation existed between the protein level and grain yield. He estimated that the protein level was governed by 22 gene pairs. In contrast to Hayes' work, Frey noted a significant effect of foreign pollen on percentage protein in the same year.

Early protein inheritance studies in wheat by Clark (4) and Clark and Quisenberry (5) indicated that the heritability for protein content was complex and highly influenced by the environment. Protein was negatively correlated with yield and positively related to awnedness. Davis *et al*. (6) studied the performance of F_2 derived lines in a replicated test and they found protein to be highly heritable and controlled by partially dominant genes for low protein. Several studies have been reported by researchers at Nebraska in which they examined crosses involving Atlas 66 which has approximately 20 percent protein. The reports by Haunold *et al*. (10,11), Stuber *et al*. (23), and Johnson *et al*. (14,15) can be summarized as follows: the protein level of Atlas 66 appeared to be under polygenic control with no indication of a preponderance of dominant genes for either high or low protein; the protein

level of F_2 mean was intermediate to both parents. They suggested a few major genes but many minor genes. Heritability estimates ranged from 0.56 to 0.83. Protein was negatively correlated with yield at low nitrogen levels and it was positively correlated with leaf rust resistance.

The environment was found to have a large influence on individual plants which was attributed to row spacing by Haunold et al. (11) and Sims (20). Stuber et al. (22) found differences in flower date and head weight to have a significant effect. Gericke (9) in 1930 found differences due to date of ripening to be a source of protein variation. Lang et al. (16) reported a reduction in protein content of corn due to higher population levels and lower nitrogen levels.

Materials and Methods

The parents used in this study were Martin, Hyderabad lines 0793 (I.S. 0075), 0819 (I.S. 2319), and 1884 (I.S. 0508). Previous research had shown that the first three named lines contained approximately 14 percent protein while 1884 had about 10 percent. Crosses were made among these lines during the summer of 1967 and F_1 plants were grown in the greenhouse in the following winter. The F_2 seed was obtained from the selfed F_1 plants. The F_1 of 0819 × 1884 was also backcrossed to each parent. This experiment was originally designed to have the following populations: Martin, 0793, 0819, 1884, (0793 × MRT) F_1 and F_2, (0819 × MRT) F_1 and F_2, (1884 × MRT) F_1 and F_2, (0793 × 0819) F_1 an F_2, (0819 × 1884) F_1 and F_2, (0819 × 1884) × 0819, and (0819 × 1884) × 1884. These populations were planted on May 2, 1968 at the Purdue University Agronomy Farm. Heavy rains and cold weather caught the seeds

just as they were germinating and killed them. The experiment was replanted the first week of June. However, the backcrosses and the F_1's of 0793 × 0819 and 0819 × 1884 could not be replanted due to the lack of seed.

The design of the experiment was a randomized complete block replicated four times. Each plot consisted of four rows 30 inches apart and 12 feet long. The plants were spaced about one foot apart within the row. The soil type was a Chalmers silty clay loam. Slightly over 250 pounds of actual nitrogen per acre was applied prior to planting. Weed control was achieved by the use of herbicides and cultivation. The herbicides were Atrazine and Ramrod applied at the rate of 2.5 and 1.5 pounds per acre, respectively.

Measurements were made on individual plants. Forty plants per plot were used for parents and F_1's while the F_2 populations consisted of every plant in the plot. The following characters were measured:

Percentage protein - calculated by multiplying 6.25 by the proportion of nitrogen determined by microkjeldahl analysis. A gram seed sample was taken from the head of the main stalk.

Flowering - number of days between planting and half bloom of the main stalk.

Leaf number - total number of leaves measured at anthesis.

Tiller number - number of stalks per plant.

Height - in cm measured at maturity.

Head exertion - in cm distance between collar of flag leaf and bottom node of the head.

Head length - in cm distance between bottom node of the head and the upper-most floret.

Head weight - in gm obtained from the main stalk.

Seed weight - in gm measured from 100 seeds.

Ten individual seeds were analyzed from each of three plants of Martin, 1884, and the F_2; 20 seeds were analyzed from each of three F_1 plants.

The data was first analyzed for differences due to replications. Then the data was checked to see if the populations had normal distributions and to see whether the means and variances were correlated in order to determine the necessity of transforming the data. Powers (19) recommended transformation if the populations were not normally distributed or if the means and variances were related. The F_2 means were compared with those of their respective parents to determine the relative amount of dominance. The F_2 variances were compared to the variances of their parents to give an indication of whether the protein determining genes were different in the various parents. Heritability in the broad sense was estimated for percentage protein using the method of Lush (18). The percentage protein values of each population were correlated with the values of the eight other characters. Table 7.6.1 of Snedecor (21) was used to determine significance of the simple correlation coefficients.

Estimates of the number of gene pairs for percentage protein was calculated using the Castle-Wright formula (3) and the Burton formula (2). The Castle-Wright formula requires the following assumptions:

1. All genes in question must have the same effects.
2. None of them can exhibit dominance.
3. The genes must combine additively.
4. Both parents must be homozygous.
5. One parent must have all of the plus genes and the other parent all of the minus genes.

6. The genes must act independently of each other.
7. Environmental differences must combine additively with genetic differences and furnish about the same amount of variance to each of the crosses and generations compared.
8. The number of individuals is large enough that sampling errors are negligible.

If the assumptions do not hold, the effect is to usually underestimate the number of genes. Only when assumptions 4 and 8 do not hold, is it possible to overestimate the number of genes but gene number can also be underestimated by failure of the last assumption. Burton's formula takes dominance into account and otherwise the assumptions are similar to that of the Castle-Wright formula.

Results and Discussion

The analysis of variance for percentage protein (Table 21) did not display a significant effect of replications, thus, there was no need to adjust the data for replication effects. The frequency distributions of the 12 populations (Table 22) appeared normal and the correlation of nonsegregating population means and variances (r=0.63 with 7 degrees of freedom) was not significant; therefore, there was no need to transform the original data. The frequency distributions of Martin, 0793, and 0819 appeared very similar while that of 1884 was different from the other three lines. The F_1 populations were generally distributed in lower percentage protein classes than their respective parents. The means of the F_2 populations was usually higher than that of the F_1 population. The frequency distributions did not exhibit discrete classes in the F_2's which indicated that percentage protein in this study had to be handled as a quantitative character.

Table 21. Analysis of variance for percentage protein of 12 populations of parents, F_1's and F_2's.

Source	D.F.	Mean Square
Replications	3	4.4272
Populations	11	76.6132**
Error	963	1.9313

**Significant at the .05 level

Based on the confidence intervals of the means (Table 23), it appeared that 0819 had a lower percentage protein than Martin or 0793. Another study showed no differences among the three lines. However, the other results came from plots not spaced compared to the spaced plants in each plot of this experiment. Thus, the differences exhibited between 0819 and Martin and between 0819 and 0793 were possibly due to an interaction of spacing on the percentage protein. The F_2's of crosses of Martin, 0793, and 0819 indicated that the protein level in each line was controlled by different genes because the magnitude of the genetic variance was large in each F_2 population. The large amounts of genetic variability came from crosses of 1884 with Martin and 0819 (no information was available about the performance of the 0793 x 1884 F_2). The large amounts of variability were reflected in the estimates of broad sense heritability which ranged from 51 to 78 percent. Since the F_1 populations usually had a lower percentage protein mean, it was not used to estimate the amount of dominance. This is in accord with Frey's (8) finding of the protein level in corn being confounded by

Table 22. Frequency distribution of percentage protein values of 12 populations of parents, F_1's and F_2's.

Population	Classes of Percentage Protein														Number of Individuals	Mean
	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
Martin				4	12	12	9	2		1					40	13.26
0793				6	10	13	7	4							40	13.36
0819				14	21	5									40	12.18
1884		14	22	4											40	10.37
0793 × MRT F_1			10	11	12	4	2	1								11.96
0793 × MRT F_2			1	9	37	48	26	22	2	2	2	2		1	152	13.86
0819 × MRT F_1		1	5	19	15										40	11.69
0819 × MRT F_2		1	21	36	48	30	27	8	2	3	1				177	12.81
1884 × MRT F_1	2	12	20	5	1										40	10.23
1884 × MRT F_2	1	8	25	38	26	14	11	5	3						131	12.09
0793 × 0819 F_2		4	13	28	31	22	8	1	1	1					109	12.36
0819 × 1884 F_2	1	9	21	40	35	16	4	2	1						129	11.92

Table 23. Means, phenotypic, environmental, and genetic variances and heritability estimates for percentage protein of 14 populations of parents, F_1's and F_2's.

Populations	Mean	Variances†			Heritability††
		Phenotypic	Environmental	Genetic	
Martin	13.26 ± 0.38	1.4506			
0793	13.36 ± 0.38	1.3867			
0819	12.19 ± 0.20	0.3839			
1884	10.37 ± 0.20	0.3768			
0793 × MRT F_1	11.96 ± 0.39	1.5201			
0793 × MRT F_2	13.86 ± 0.26	2.7495	1.4694	1.2801	47%
0819 × MRT F_1	11.69 ± 0.22	0.4948			
0819 × MRT F_2	12.81 ± 0.24	2.6105	0.7060	1.9045	73%
1884 × MRT F_1	10.23 ± 0.27	0.7125			
1884 × MRT F_2	12.09 ± 0.27	2.5364	0.8131	1.7233	68%
0793 × 0819 F_1	11.63‡				
0793 × 0819 F_2	12.36 ± 0.26	1.8242	0.8853	0.9389	51%
0819 × 1884 F_1	11.98‡				
0819 × 1884 F_2	11.92 ± 0.23	1.7588	0.3804	1.3784	78%

†The environmental variances of F_2's were obtained from the average phenotypic variances of parents and F_1. Genetic variance was estimated by subtracting the environmental variance from the F_2 phenotypic variance.

††Heritability in the broad sense was estimated by dividing the genetic variance by the phenotypic F_2 variance.

‡The means of 0793 × 0819 F_1 and 0819 × 1884 F_1 were obtained from a separate experiment.

heterosis for grain yield in the F_1. Even though the F_2 populations should show only 50 percent of the dominance found in the F_1 population, they were used to estimate the amount of dominance because they should also show less heterosis for grain yield. The mean of 0793 × Martin F_2 was similar to both parents. Partial to full dominance for high protein was indicated by the four other F_2 populations.

Both Castle-Wright and Burton formulas were used to derive the estimates of gene numbers shown in Table 24 because previous studies had indicated that gene action for percentage protein was mainly additive while the results of this experiment suggested that dominance existed for the protein level. The material must not have fit all of the assumptions because the Castle-Wright formula gave extremely small values. Perhaps the relative magnitude of the values are of significance. The value was very small for the cross between 0793 and Martin and it was relatively small for the crosses of 0819 with 0793 and Martin. Large values came from crosses of 1884 with Martin and 0819.

Phenotypic correlation coefficients are presented in Table 25. Protein was usually correlated with tiller number, height, head weight, and flowering. Higher protein was usually found in short, early flowering plants with several tillers. Although the parent and F_1 populations seldom showed a significant correlation with head size, all of the F_2 populations did show a highly significant negative association. This may have been the result of segregation of genes for grain yield and percentage protein which were linked in repulsion. However, it could have been due to plants retaining the most heterosis for grain yield and were lower in percentage protein than those plants which had become homozygous for the yield genes.

Table 24. Number of gene pairs for percentage protein in five F_2 populations estimated by the Castle-Wright† formula and the Burton†† formula.

F_2 Populations	Number of Gene Pairs	
	Castle-Wright	Burton
0793 × Martin	0.001	0.372
0819 × Martin	0.068	0.194
1884 × Martin	0.572	0.917
0793 × 0819	0.182	0.531
0819 × 1884	0.300	0.389

†Castle's formula:

$$n = \frac{D^2}{8(S^2F_2 - S^2F_1)}$$

Where: n is number of gene pairs,

D is the mean difference of the parents, and

S^2F_2 and S^2F_1 are the variances for F_2 and F_1, respectively.

††Burton's formula:

$$n = \frac{0.25\ (0.75 - h + h^2)\ D^2}{S^2F_2 - S^2F_1}$$

Where: $h = \overline{F}_1 - \overline{P}_1 \div \overline{P}_2 - \overline{P}_1$

$D = \overline{P}_2 - \overline{P}_1$

$\overline{P}_1$ = mean of smaller parent

$\overline{P}_2$ = mean of larger parent

$\overline{F}_1$ = mean of first generation

$\overline{F}_2$ = mean of second generation

Table 25. Phenotypic correlation coefficients of percentage protein with eight other characters in 12 populations of parents, F_1's and F_2's.

Population	D.F.	Correlation Coefficient							
		Leaf No.	Tiller No.	Height	Head Exert.	Head Length	Head Wt.	Seed Wt.	Flowering
Martin	38	-0.54**	0.15	-0.54**	0.15	0.26	0.02	-0.20	-0.43**
0793	38	0.10	0.31*	-0.44**	-0.39*	0.27	-0.25	-0.28	-0.44**
0819	38	0.20	0.02	-0.24	-0.31*	-0.08	-0.33*	-0.12	-0.16
1884	38	0.28	0.42**	0.08	-0.11	0.03	-0.02	-0.29	0.48**
0793 × MRT F_1	38	-0.21	0.63**	-0.44**	-0.20	0	-0.06	0.13	-0.24
0793 × MRT F_2	150	-0.38**	0.14	-0.52**	-0.07	-0.17	-0.58**	-0.33**	-0.38**
0819 × MRT F_1	38	0.50**	0.37*	-0.27	0.05	-0.24	-0.31*	0.21	-0.07
0819 × MRT F_2	175	-0.10	0.20*	-0.41**	-0.10	-0.12	-0.55**	-0.17	-0.14
1884 × MRT F_1	38	-0.32*	0.69**	-0.54**	-0.09	0.07	0.29	0.32*	-0.25
1884 × MRT F_2	129	-0.07	0.23**	-0.13	0.11	-0.23**	-0.52**	0.16	-0.23**
0793 × 0819 F_2	107	-0.10	0.29**	-0.27**	-0.04	0.08	-0.43**	-0.20*	-0.22*
0819 × 1884 F_2	127	0.27**	0.18	0.15	-0.01	-0.25**	-0.35**	-0.21*	0.22*

*Significant at the .05 level.
**Significant at the .01 level.

The plants which had more than 16 percent protein alwa[illegible] [illegible] [illegible]l head weights (less than 50 grams). Almost always those plants with head weights larger than 180 grams were low in protein (less than 12 percent). However, there were many plants which had head weights of less than 50 grams and contained low levels of protein. Plants having more than 13 percent protein were generally restricted to head weights of 100 grams or less, but there were several plants which had exceptional combinations. The plant with the best combination had 13.48 percent protein in a 170 gram head.

The F_2 of 0793 × Martin had segregates with the highest levels of protein. If one selected only on the basis of percentage protein, the 0793 × Martin cross would be the best population to use for selection. However, 0793 and Martin have been shown in previous work to be low in lysine (about 1.9 percent) while 0819 and 1884 were higher in lysine (about 2.7 percent). Thus, selection for both protein quantity and quality could be more easily accomplished in the cross of 0819 × 1884 or in crosses of 0793 or Martin with 0819 or 1884.

This study should be carried on for at least another year. Lines of F_3 from F_2 plants should be grown next year. More accurate measurements for yield, percentage protein, and percentage lysine could be obtained from the F_3 lines grown in a replicated test. The results from the F_3 lines should give a better basis for determining the inheritance of protein quantity and quality.

Results are shown in Table 26 of the single seed analysis for percentage protein from three plants of each population of Martin, 1884, 1884 × Martin F_1, and 1884 × Martin F_2. Wide variation existed for percentage protein among these lines. The objective of this part

Table 26. Means and variances of single seed analysis for percentage protein of three plants of Martin, 1884, 188′ × MRT F_1, and 1884 × MRT F_2.

Population	Plant	Number of Seed Analyzed	Mean	Variance
Martin	1	10	14.58 ± 0.40	0.3161
	2	10	13.76 ± 0.54	0.5691
	3	10	12.61 ± 0.50	0.4850
1884	1	10	11.21 ± 0.15	0.0418
	2	10	9.76 ± 0.44	0.3857
	3	10	10.49 ± 0.23	0.2318
1884 × MRT F_1	1	20	12.70 ± 0.29	0.3727
	2	20	9.65 ± 0.23	0.2494
	3	20	10.49 ± 0.23	0.2318
1884 × MRT F_2	1	10	13.12 ± 0.41	0.3261
	2	10	15.35 ± 0.39	0.2962
	3	10	10.06 ± 0.75	1.1007

of the study was to determine the feasibility of using single seeds for genetic studies. Variation among seeds of each plant of the two parents should be due only to environmental influences and error of chemical analysis. The F_1 should show variability due to genetic segregation plus that variation found in the parents. The F_2 should behave similarly to the F_1, but the amount of genetic variability should be less. However, the F_1 variance values were not larger than those of the parents. The amount of plant to plant variation was large in each population which was not surprising because of similar findings in previous work. One must conclude from these results that single seeds can not be used for genetic studies because the maternal influence, which is quite sensitive to the environment, apparently controls the

level of protein in the grain. The effect of the environment on the plant must limit the amount of nitrogen that can be translocated in each seed. Thus the different genotypes in the embryo and endosperm of the seed from the F_1 plant can not be distinguished from each other.

Summary and Conclusions

Space planted individual plant performance of each parent, F_1, and F_2 populations of five sorghum crosses was investigated in order to elucidate the inheritance of percentage protein. The lines used for this study were Martin, Hyderabad lines 0793, 0819, and 1884 which represented three lines having significantly better than average proteins levels and a low protein line, respectively. Martin and 0793 were about equal in protein level; they had 13.26 $\pm$ 0.38 and 13.36 $\pm$ 0.38 percent protein, respectively. Line 0819 had 12.19 $\pm$ 0.20 percent protein which was significantly lower than the previous two. Line 1884 had only 10.37 $\pm$ 0.20 percent protein. The F_1 means were always lower than either parent while the F_2 means were either equal to the high parent or intermediate between the parents. Since heterosis for yield was expressed in the F_1, the mean of the F_2 was used to estimate dominance because there was a negative correlation between yield and percentage protein. Thus the F_2 exhibited partial to complete dominance for high percentage protein. Broad sense heritabilities ranged from 47 to 78 percent. The variances of the F_2's indicated that each parent had different genes for controlling the protein level.

The number of genes pairs estimated by formulas of Castle-Wright and Burton appeared to be few. The estimates from the former formula were more consistent with the F_2 variances than were those from the

Burton formula. The smallest estimate came from the Martin by 0793 cross; low estimates came from crosses of 0819 with Martin and 0793; and larger estimates of gene pairs were obtained from crosses of 1884 with 0819 and Martin.

Percentage protein generally appeared to be positively correlated with tiller number and negatively associated with date of flowering. There was a highly significant negative correlation between head weight and percentage protein in every F_2 population but only two significant cases of their correlation in the seven parent and F_1 populations. This phenomenon can be explained by either a segregation of protein and yield genes which were linked in repulsion or it may have been due to a part of the F_2 population showing heterosis for yield and consequently being low in protein, similar to the F_1, and the remainder of the F_2 population showing higher protein levels in lower yielding, relatively homozygous genotypes.

The inheritance of percentage protein was investigated in the cross of Martin by 1884 using single seeds for chemical analysis. Seed were taken from three plants of Martin, 1884, the F_1, and the F_2. The variability among seeds from the same plant and between plants of the parents and the F_1 should have been due only to environmental factors, assuming the parents were homozygous. Genetic variability should have been found particularly among seed of the same F_1 plant and, perhaps to a lesser degree, in the F_2 plants. However, there was no evidence for genetic variability among the seed of the F_1 plant which actually represented F_2 seed. Therefore, it appears that the protein level of single seeds can not be considered representative of the genotype of the embryo.

The overall results suggest that several genes for protein exist and that they can be combined. Individual F_2 plants were found which had superior levels of protein and large heads which indicates that high yielding - high protein genotypes can be selected from these F_2's.

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SECTION III

ENVIRONMENTAL EFFECTS ON PERCENTAGE PROTEIN

SORGHUM BICOLOR (L.) MOENCH

SECTION III

ENVIRONMENTAL EFFECTS ON PERCENTAGE PROTEIN IN *SORGHUM BICOLOR* (L.) MOENCH

Introduction

Early research on protein quantity and quality at Purdue was hampered by poor repeatability of percentage protein determinations. The technique used in the chemical analysis of the seed was found not to be the source of the error because remarkable repeatability (0.63 percent) for percentage protein could be achieved from the same seed source. Thus the problem became one of obtaining a representative seed sample and control of environmental influences. Initial results disclosed a considerable amount of variability existed among plants of the same line grown in the same plot and among years and plant populations.

Several experiments were carried out in an effort to located the source or sources of variability. One study involved comparing the percentage protein values of individual plants selected from a uniform appearing line with those values determined from their progeny. This comparison should indicate the reliability of protein values from individual heads. If the values are reliable, the breeding program for increasing percentage protein can be accelerated by selecting on the basis of individual plant performance.

Another experiment was designed to determine the effects of bagging (selfing) and flag leaf removal on grain yield and percentage protein. Plants in the nursery were selfed by placing a bag over the head before

anthesis to protect against foreign pollen. The normal method of bagging is to remove the flag leaf and place a bag over the head. Since photosynthesis occurs in the flag leaf and in the head, grain yield may be reduced by selfing and percentage protein may be increased because of the negative correlation between percentage protein and yield that has generally been observed. This may be reflected in a smaller seed size which could be due to a smaller endosperm.

A third experiment was performed to elucidate the effects of harvest stage on percentage protein. If a killing frost occurred before the seed were mature, percentage protein would be expected to be higher. A delay in harvesting until winter because of bad weather may influence the percentage protein in the seed.

The effects of growing the same genotypes at different locations and in different years were studied in a fourth experiment. If location effects or interactions of genotypes with locations or years or both exist, it would indicate the necessity of more extensive testing of the genotypes.

Review of Literature

Stickler and Pauli (15) found a curvilinear relationship between grain yield and leaf area. Number of seeds per head and seed weight were affected when leaf area was reduced. Yield was reduced more by removing the leaf area from the upper than lower portions of the plant; it was decreased by 23, 35, 43, and 95 percent when 33, 50, 67, and 100 percent, respectively, of the leaves were removed at the boot stage or anthesis. Pauli and Stickler (13) reported a decrease in total accumulation of nitrogen by plants of Plainsman grain sorghum after

defoliation. If all the leaves were removed, the total nitrogen in the grain was reduced by 90 percent; however, percentage nitrogen was increased significantly in the grain. The increased nitrogen level was apparently caused by a lack of normal carbohydrate accumulation and subsequent seed development. Urie et al. (17) found that leaf removal from safflower plants reduced yield and seed weight but increased oil percentage. They found a differential response among genotypes.

Frøst and Ellerstrom (4) studied the relationship between protein content and other characters in tetraploid rye. They reported finding a positive correlation between degree of shrinkage and percentage protein. This should be comparable with injury from an early frost on sorghum grain.

The effect of growing sorghum at different locations on the protein level in the seed is well documented in the literature. Lowe (8) noted a higher protein level in grain grown on fallow ground than in the grain grown under irrigated conditions. The protein level of genotypes studied by Malm (10) varied considerably between the two years in which he grew his experiment. Miller et al. (11) reported significant differences existed for location and varieties. They found that both protein content and yield were increased by nitrogen fertilization. Deyoe and Shellenberger (3) obtained variations in protein content and amino acid composition which were due to hybrids and locations. Waggle et al. (18) reported significant increases in protein and 17 amino acids from nitrogen fertilization; the distribution of the amino acids was also significantly affected. The proportions of glutamic, proline, alanine, isoleucine, leucine, and phenylalanine were increased while the proportions of lysine, histidine, arginine, threonine, and glycine were

decreased. Nitrogen fertilization was also found by Campbell and Pickett (2) to increase protein but it did not significantly affect lysine as a percent of protein; however, lysine was lower and protein was higher at a location maintained under very high fertility levels compared to a location under good fertility management. Liang and Walter (7) studied the interactions of genotype with the environment on yield; the genotype by location and the genotype by year interactions were significant but their relative components were small compared with the second order interaction of genotype × location × year and genetic variance. The large second order interaction indicated a differential response of genotypes grown under different environmental conditions. They felt that results from single experiments could not be considered adequate for hybrid recommendation.

The influence of the environment on protein content has also been measured in other crops. MacGregor et al. (7) found no significant effect of nitrogen fertilization on the content of lysine, methionine, or threonine in corn grain. Bhatty et al. (1) found significant differences in the nutritive value of wheat due to variety, location, and year. Wood and Fox (19) studied the interaction of nitrogen and irrigation on yield and protein in wheat grown in Queensland, Australia. Irrigation increased protein yield for every treatment other than the no nitrogen treatment. Application of nitrogen increased protein in every instance. When nitrogen was applied at sowing, yield was increased while percentage protein was increased when the nitrogen was applied at the time of flowering. Sims (14) and Haunold et al. (6) attributed a large environmental influence on the protein level in individual wheat plants to row spacing. Flowering date and head weight were reported by

Stuber *et al.* (16) to have a significant effect on protein in wheat. Gericke (5) found differences due to date of ripening to be a source of protein variation in wheat.

Materials and Methods

This study consisted of four separate experiments; each experiment was designed to reveal the effect of a particular environmental treatment on the percentage protein of the grain in every case and grain yield in two of the experiments.

Experiment I: Plant to Plant Variation Within a Line

Hyderabad line 0819 (I.S. 2319) was chosen for this experiment because it appeared to be homozygous at least for all genes affecting its morphological characters. Seven plants were randomly chosen from it and the selfed seed from each plant was analyzed for protein. Each selection was grown at the Purdue University Agronomy Farm in the summer of 1967. The design was a randomized complete block replicated four times. Each plot was a single 38 inch row 15 feet long. The soil type was a Chalmers silty clay loam. Anhydrous ammonia at the rate of 194 pounds of actual nitrogen per acre and a mixed fertilizer of 8-32-16 at the rate of 170 pounds per acre were applied prior to planting. Plants were thinned to 120,000 plants per acre where stands were sufficient.

Grain from the entire plot was harvested and analyzed for protein; yield was not measured due to inadequate stands. Seed for chemical analysis was obtained by taking a sample from the threshed seed of each plot. Percentage protein was calculated by multiplying 6.25 by the proportion of nitrogen determined by microkjeldahl analysis. The

data was statistically analyzed for differences among the progeny of the selections. The percentage protein value of the parent was correlated with the percentage protein mean value of the progeny of each selection to show the relationship between the two values.

Experiment II: Effects of Bagging and Flag Leaf Removal

The genotypes used in this study were RS610, Hyderabad line 0819 (I.S. 2319), Hyderabad line 1884 (I.S. 0508), Redlan × 0819, and Redlan × 1884. The treatments were:

Treatment Number	Treatment
1	Control.
2	Flag leaf removed only.
3	Head bagged only.
4	Flag leaf removed and head bagged.

The experiment was grown in 1967 and 1968 at the Purdue University Agronomy Farm. The design in both years was a randomized complete block replicated four times. In 1967 each plot consisted of two rows 38 inches apart and 15 feet long while the rows were 30 inches wide in 1968. The study was grown on a similar Chalmers silty clay loam soil each year and the fertility conditions were similar. Slightly over 200 and 250 pounds per acre of actual nitrogen were applied prior to planting in 1967 and 1968, respectively. The weed control methods did differ between years; it was achieved by conventional cultivation means in 1967 and by conventional and herbicide in 1968. The herbicide used in 1968 was Atrazine and Ramrod applied at the rate of 2.5 and 1.5 pounds per acre, respectively. Plants were thinned to similar stands of approximately 100,000 plants per acre both years; actual stands at harvest ranged from 60,000 to 90,000 heads per acre.

Grain yield was determined by harvesting 10 feet from each row of the plot. Percentage protein was calculated by multiplying 6.25 by the proportion of nitrogen determined by microkjeldahl analysis. Seed weight was determined from the weight of 100 seeds. Statistical analyses involved analysis of variance for each character.

Experiment III: Effect of Harvesting at Various Stages

The genotypes used in this study were RS610, AKS614, Hyderabad line 0819 (I.S. 2319), and Hyderabad line 1884 (I.S. 0508). The harvest stages were as follows:

Stage Number	Harvest Stage
1	Approximately milk stage
2	10 days after milk stage
3	20 days after milk stage
4	30 days after milk stage
5	60 days after milk stage
6	90 days after milk stage
7	120 days after milk stage

The experiment was grown on the Purdue University Agronomy Farm in 1967. The design was a randomized complete block replicated four times. Each plot consisted of two rows 38 inches apart and 15 feet long. The soil type was a Chalmers silty clay loam. Approximately 200 pounds per acre actual nitrogen was applied prior to planting. The earliest harvest stage began in early August and the latest stage was harvested in early January. The threshed grain of each plot was sampled for protein analysis. Percentage protein was calculated by multiplying 6.25 by the proportion of nitrogen determined by microkjeldahl analysis.

An analysis of variance was performed to determine the significance of differences in percentage protein at the different harvest stages.

Experiment IV: Effects of locations and Years

Eleven genotypes which exhibited a 10 to 18 percent range in percentage protein were grown at three locations in 1967 and 1968. The genotypes were RS610, Redlan B, Wheatland B, Combine Kafir B, Martin B, Hyderabad lines 0026 (I.S. 3126), 0355 (I.S. 1259), 0793 (I.S. 0075), 0819 (I.S. 2319), 1884 (I.S. 0508), and 5187 (I.S. 8364). The three locations were the Purdue University Sand Farm and two locations on the Purdue University Agronomy Farm; one represented a soil maintained under a very high fertility level for many years and another maintained under a normal level of fertility. The locations on the Agronomy Farm were designated as High Fertility for the former and Nursery for the latter.

Each year the Sand Farm had 200 pounds per acre of 0-0-60 plowed down, 150 pounds per acre of 8-32-16 as a starter fertilize, and 150 pounds per acre of actual nitrogen side dressed in three applications; the last application was made prior to heading. Each plot consisted of two rows 36 inches apart and 15 feet in length. Weed control was accomplished by use of Atrazine and cultivation. The experiment was irrigated as needed. The High Fertility location received approximately 400 pounds per acre of actual nitrogen each year while the Nursery received about 200 and 250 pounds of actual nitrogen per acre in 1967 and 1968, respectively. The soil type of the High Fertility and Nursery was a Chalmers silty loam. Each plot in 1967 consisted of two rows 38 inches apart and 15 feet long but in 1968 the row widths were reduced

to 30 inches. Weeds were controlled in 1967 by conventional methods and in 1968 they were controlled through the use of Atrazine and Ramrod and later cultivation. Plants were thinned to similar populations of around 100,000 plants per acre at each location in 1967 and 1968. Final stands at the Sand Farm were around 100,000 plants per acre while they were 60,000 to 90,000 at the High Fertility and Nursery locations.

The design at all locations was a randomized complete block replicated four times. Grain yield was determined from 10 feet harvested from each row of the plot. The grain from each plot was sampled for protein analysis. Percentage protein was calculated by multiplying 6.25 by the proportion of nitrogen determined from microkjeldahl analysis. Protein yield was calculated by multiplying the percentage protein by grain yield. A statistical model similar to the one used by Miller *et al*. (12) was used for the pooled analysis of variance.

Results and Discussion

Experiment I: Plant to Plant Variation Within a Line

The percentage protein values of the grain obtained from each selected parent and the progeny of each selection are presented in Table 27. The sample for protein analysis was taken from a single selfed head for each selection and the sample from the progeny of each selection was obtained from the bulked seed of all the plants in a plot. The range of values of the parents was 12.47 to 16.75 percent while the range of the progeny means was only 13.34 to 14.01 percent. The former had a C.V. of 27.37 percent while the latter had a C.V. of only 0.90 percent. The correlation between the means of the progeny with the values of their respective parents was a nonsignificant 0.07.

Table 27. Percentage protein of seven selections of Line 0819 grown in 1967.

Selection	Percentage Protein					
	Selfed Parent	Replication				Mean of Four Replications
		I	II	III	IV	
0819-1	16.75	14.03	13.94	14.28	13.78	14.007
0819-2	16.09	14.03	13.25	13.38	13.28	13.485
0819-3	13.53	13.81	14.06	13.06	13.72	13.663
0819-4	14.88	13.94	13.84	13.41	13.34	13.633
0819-5	15.94	13.97	13.88	13.91	13.47	13.808
0819-6	14.22	13.91	13.69	13.63	13.53	13.690
0819-7	12.47	13.50	13.53	13.00	13.34	13.343

There was a significant difference between progeny which was shown by the magnitude of the variation due to selections in the analysis of variance (Table 28).

Table 28. Analysis of variance of seven selections from Line 0819 for percentage protein.

Source	d.f.	Mean Square
Replications	3	0.2222*
Selections	6	0.1749*
Error	18	0.0611
C.V. =	0.90%	

These results suggest that the plant to plant variation within a line is so large that the protein level in a single plant cannot be regarded as being representative of the line or even as an indication of the performance of the progeny of that head. Since the environment of a plant does appear to influence the protein level to such a large degree, a seed sample taken from several plants should have a level of protein more representative of that particular line than a sample taken from a single head.

Experiment II: Effects of Bagging and Flag Leaf Removal

Results of the pooled analyses of variance for grain yield, percentage protein, and seed weight are shown in Table 29. These analyses displayed a significant effect over the two years of the various treatments on grain yield and percentage protein. Even though the pooled analysis for seed weight did not display a significant treatment effect nor a year by treatment interaction, the 1967 data did show a significant effect of bagging on seed size. The treatment means (Table 30) for grain yield show decreases due to removing the flag leaf and to bagging the head. When the two treatments were combined, their effects seemed to be additive as indicated by the amount of reduction that they caused. Bagging the head appeared to increase the percentage protein of the seed while flag leaf removal apparently had no effect on the protein level. In 1967 seed weight was also increased slightly by placing a bag over the head. Varietial means (Table 31) for grain yield were larger in 1968 than in 1967 while means of percentage protein were lower in 1968 than in 1967.

Table 29. Pooled analyses of variance for grain yield, percentage protein, and 100 seed weight of the effects of bagging and flag leaf removal experiment grown in 1967 and 1968.

Sources of Variation	d.f.	Mean Squares			
		Grain Yield	Protein Yield	% Protein	100 Seed Wt.
Years	1	18,236,472**	25,067*	46.537**	0.3572
Blocks in Years	6	1,053,054	14,319	0.118	0.1305
Varieties	4	20,178,738**	211,812**	17.303	4.8020**
Treatments	3	15,307,308**	190,621**	4.152*	0.1203
V × T	12	910,666**	13,727	0.669	0.0603
V × Y	3	2,341,721**	49,332**	50.234**	0.6898**
T × Y	3	454,571	8,495	0.142	0.1140
V × T × Y	12	637,672	16,617**	1.189**	0.0253
Error	116	351,025	3,964	0.193	0.0468

*Significant at the .05 level.
**Significant at the .01 level.

Table 30. Treatment means for grain yield, protein yield, percentage protein, and 100 seed weight of the effects of bagging and flag leaf removal experiment grown in 1967 and 1968.

Treatment	Grain Yield (kg/ha)			Protein Yield (kg/ha)			% Protein			100 Seed Wt. (gms)		
	1967	1968	Mean	1967	1968	Mean	1967	1968	Mean	1967	1968	Mean
1	7600	9141	8371	523.8	508.9	516.4	11.80	10.56	11.18	2.73	2.88	2.81
2	6951	8142	7547	467.8	458.9	463.4	11.65	10.69	11.17	2.70	2.90	2.80
3	6118	6322	6220	434.7	366.2	400.5	12.55	11.18	11.72	2.88	2.95	2.92
4	5076	6098	5587	363.5	355.7	359.6	12.27	11.23	11.75	2.90	2.85	2.88
LSD_{05}	469	871	465	50.3	53.3	62.8	0.28	0.17	0.53	0.12		
LSD_{01}	625	1160	652	67.0	71.0	88.1	0.37	0.22				

Table 31. Varietal means for grain yield, protein yield, percentage protein, and 100 seed weight of the effects of bagging and flag leaf removal experiment grown in 1967 and 1968.

Variety	Grain Yield (kg/ha)			Protein Yield (kg/ha)			% Protein			100 Seed Wt. (gms)		
	1967	1968	Mean	1967	1968	Mean	1967	1968	Mean	1967	1968	Mean
RS610	4737	5128	4933	347.3	310.3	328.8	12.49	11.56	12.03	2.41	2.37	2.39
0819	5305	7714	6510	450.9	423.5	437.2	14.49	12.18	13.34	3.23	3.25	3.24
Redlan × 0819	8370	9274	8822	605.1	457.4	531.2	12.28	11.15	11.72	3.08	3.40	3.24
1884	5942	6354	6148	359.3	409.6	384.4	10.29	10.33	10.31	2.58	2.59	2.59
Redlan × 1884	7828	8611	8220	474.8	511.4	493.1	10.41	9.34	9.88	2.70	2.86	2.78
LSD_{05}	525	974	943	56.2	59.6	121.0	0.31	0.19		0.13	0.12	
LSD_{01}	699	1297	1323	74.9	79.4	169.6	0.42	0.25		0.17	0.16	

Since selfed seed contained higher protein levels than open-pollinated seed, bagging the heads in order to maintain genetic purity will probably bias the percentage protein values upward. It is interesting to note that flag leaf removal did not affect the protein level even though yield was decreased. It was also somewhat surprising that protein was not increased to a larger extent considering the severe reduction in yield. The lack in compensation for percentage protein in lower yields was reflected in reduction in protein yield. Perhaps the most significant information derived from this experiment relates to the effects of flag leaf removal and bagging the head on grain yield. The head and flag leaf are apparently major sources of photosynthetic products which are translocated to the seed.

Experiment III: Effect of Harvesting at Various Stages

The harvest stage component of variance (Table 32) was highly significant and it was apparently caused by a higher protein level in the seed which were harvested at the milk stage (Table 33). Harvesting the seed at various dates from the dough stage to four months later did not affect the protein level. A significant variation of 11.10 to 14.08 percent existed among genotypes (Table 34). The significant interaction between genotypes and harvest stages appeared to be caused by harvesting 0819 after the intended milk stage in the first harvest (Appendix Table 5).

The results of this experiment suggest that a delay in harvesting will not decrease the quantity of protein in the seed after it has matured. However, the seed will contain a higher proportion of protein if the plants are killed by an early frost and the seed have not

Table 32. Analysis of variance for percentage protein of four sorghum genotypes harvested at seven different stages of maturity in 1967.

Source of Variation	d.f.	Mean Square
Blocks	3	0.5689
Genotypes	3	42.2459**
Harvest Stages	6	3.5798**
Genotypes × H.S.	18	1.0225**
Error	81	0.1867
C.V. = 3.46%		

*Significant at the .05 level.
**Significant at the .01 level.

Table 33. Means of percentage protein of seven harvest stages of four sorghum genotypes grown in 1967.

Harvest Stage	% Protein Mean
#1	13.52
#2	12.49
#3	12.20
#4	12.29
#5	12.19
#6	12.24
#7	12.39
LSD_{05}	0.304
LSD_{01}	0.403

Table 34. Means of percentage protein of four sorghum genotypes harvested at seven stages of maturity in 1967.

Genotype	% Protein Mean
RS610	12.27
AKS614	12.45
0819	14.08
1884	11.10
LSD_{05}	0.230
LSD_{01}	0.305

completely developed. Thus, the protein values obtained from the chemical analysis of immature seed will probably be biased upward.

Experiment IV: Effects of Locations and Years

The pooled analysis of variance for grain yield, percentage protein, and protein yield of the eleven genotypes over the three locations and the two years are presented in Table 35. The significant effects of years and locations were expected for the yield measurements but their effect on percentage protein was not well documented on sorghum which had a range in protein level that existed in this experiment. The first order interactions of varieties with years and locations were not significant for any of the characters. The second order interaction of genotypes × locations × years was highly significant for each character. The yearly means (Table 36) indicated a larger grain yield and protein yield and a smaller protein level in 1968 than in 1967. The eleven genotypes used in this study performed the best at the Nursery location (Tables 37, 38 and 39); they performed the poorest for all three

Table 35. Pooled analyses of variances for grain yield percentage protein and protein yield of 11 sorghum genotypes grown in three locations in 1967 and 1968.

Source of Variation	d.f.	Mean Squares		
		Grain Yield	% Protein	Protein Yield
Years	1	9,550,713**	86.0114**	59,031**
Locations	2	20,860,678**	25.5164**	324,793**
Genotypes	10	7,307,737**	107.9268**	112,499**
Blocks in Loc and Yrs	18	112,466	10.5782**	20,724**
Year × loc.	2	101,572	22.6966**	166,644**
Gen × year	10	1,129,345	1.8931	8,618
Gen × loc.	20	136,566	0.7582	8,557
Gen × loc. × yr.	20	909,298**	0.9915**	7,198**
Error	160	269,141	0.0607	1,817

**Significant at the .01 level.

Table 36. Yearly means of grain yield, percentage protein, and protein yield of 11 sorghum genotypes grown in 1967 and 1968 at three locations.

Genotype	Grain Yield (kg/ha)		% Protein		Protein Yield (kg/ha)	
	1967	1968	1967	1968	1967	1968
0026	5062	6206	14.8	13.9	791	766
0355	2559	2119	17.9	16.9	493	317
0793	5501	7549	14.8	12.8	861	868
0819	4635	6749	14.4	12.5	705	761
1884	4445	6661	11.3	9.9	521	597
5187	3699	3489	11.4	10.6	440	327
Martin	4610	4789	13.9	12.9	673	543
CK60	4890	5393	11.0	10.0	564	483
Wheatland	4661	5325	12.2	10.8	595	503
Redlan	5555	5946	11.7	11.0	682	580
RS610	5794	6043	11.7	10.6	709	583
Mean	4672	5478	13.2	12.0	639	575

Table 37. Means of grain yield (kg/ha) of 11 sorghum genotypes grown at three locations in 1967 and 1968.

Genotype	Sand Farm			Hi-Fertility			Nursery			Mean of All Tests
	1967	1968	Mean	1967	1968	Mean	1967	1968	Mean	
0026	2729	4395	3563	5961	7626	6795	6491	6593	6543	5634
0355	1085	1355	1220	2951	1894	2423	3638	3106	3373	2339
0793	3046	6606	4827	6634	7538	7088	6818	8497	7659	6525
0819	2777	6600	4684	4495	6927	5712	6630	6726	6679	5692
1884	2865	6225	4546	4258	6126	5193	6209	7629	6920	5553
5187	3445	2457	2951	3235	2553	2895	4413	5455	4935	3594
Martin	3916	3250	3583	4674	4863	4769	5238	6251	5746	4700
CK60	4236	4875	4556	4251	4856	4554	6181	6446	6314	5142
Wheatland	4077	3605	3842	5253	5333	5294	4650	7033	5843	4993
Redlan	4738	4392	4566	6091	6273	6183	5831	7168	6501	5750
RS610	5318	5868	5594	5754	5933	5845	6307	6325	6317	5919
Mean	3477	4511	3993	4870	5448	5158	5674	6476	6074	5074
LSD_{05}	643	812		962	1223		800	1265		
LSD_{01}	866	1093		1295	1646		1077	1702		
C.V.	12.8%	5.9%		13.7%	7.8%		9.7%	6.8%		

Table 38. Means of percentage protein of 11 sorghum genotypes grown at three locations in 1967 and 1968.

Genotype	Sand Farm			Hi-Fertility			Nursery			Mean of All Tests
	1967	1968	Mean	1967	1968	Mean	1967	1968	Mean	
0026	14.3	13.2	13.7	14.5	13.6	14.0	15.7	14.9	15.3	14.3
0355	16.4	16.4	16.4	18.8	17.0	17.9	18.6	17.4	18.0	17.4
0793	14.0	12.5	13.2	15.0	12.4	13.7	15.3	13.5	14.4	13.8
0819	13.4	12.3	12.8	15.2	11.8	13.5	14.6	13.4	14.0	13.4
1884	11.4	9.8	10.6	11.1	9.8	10.5	11.3	10.1	10.7	10.6
5187	10.2	10.5	10.3	12.0	10.7	11.3	12.1	10.7	11.4	11.0
Martin	12.1	13.4	12.8	14.5	12.4	13.4	15.1	12.8	14.0	13.4
CK60	9.6	9.7	9.6	11.7	9.8	10.8	11.7	10.5	11.1	10.5
Wheatland	11.1	11.7	11.4	12.4	10.3	11.3	13.2	10.4	11.8	11.5
Redlan	10.2	11.6	10.9	12.1	10.6	11.3	12.8	10.8	11.8	11.3
RS610	10.5	10.6	10.6	12.0	10.4	11.2	12.6	11.0	11.8	11.2
Mean	12.1	12.0	12.0	13.6	11.7	12.6	13.9	12.3	13.1	12.6
LSD_{05}	1.22	0.59		0.58	0.93		0.57	0.69		
LSD_{01}	1.64	0.79		0.78	1.25		0.77	0.93		
C.V.	7.0%	1.7%		3.0%	2.8%		2.8%			

Table 39. Means of protein yield (kg/ha) of 11 sorghum genotypes grown at three locations in 1967 and 1968.

Genotype	Sand Farm			Hi-Fertility			Nursery			Mean of All Tests
	1967	1968	Mean	1967	1968	Mean	1967	1968	Mean	
0026	389	612	500	909	867	888	1075	819	948	779
0355	178	234	206	587	267	427	714	451	583	405
0793	427	868	648	1049	782	915	1106	953	1029	864
0819	373	853	613	718	679	699	1023	750	887	733
1884	326	647	486	500	502	501	737	642	690	559
5187	348	271	310	409	225	317	564	483	524	384
Martin	473	460	467	712	502	607	835	666	751	608
CK60	400	497	449	527	398	462	765	555	660	524
Wheatland	453	441	447	686	457	572	647	610	628	549
Redlan	483	540	512	777	554	665	784	647	716	631
RS610	562	658	610	726	515	621	839	576	707	646
Mean	401	553	477	691	522	607	826	650	738	607
LSD_{05}	81	99		135	122		127	123		
LSD_{01}	110	133		181	164		171	165		
C.V.	7.0%	6.2%		6.8%	8.1%		5.3%	6.5%		

characters at the Sand Farm. The interaction of genotypes within locations and years can be found in the tables by comparing the relative rank of each genotype for each environment.

These results imply that the genotypes should be tested for more than one year at the locations where they are intended to be grown rather than making inferences to their performances at other locations based on one year's data obtained from one location. Although the genotypes did not respond similarly at each location each year, the high protein genotypes contained high protein levels under each situation and the low protein genotypes had low protein levels in every case.

NO!!! only if significant genotype x Loc int.

Summary and Conclusions

Four experiments were conducted to determine the effects of specifi treatments and environments on percentage protein. The first experiment involved the comparison of the percentage protein values of seven single plant selections with the mean value of their progeny. The results indicated that the percentage protein value obtained from a single plant may not be very reliable. A more reliable estimate can be obtained from a sample taken from several plants. Another experiment was designed to determine the effects of bagging the head and flag leaf removal on yield and percentage protein of five genotypes. Percentage protein was increased by bagging the head before anthesis. Bagging the head and removing the flag leaf just before anthesis caused drastic reductions (33 percent) in grain yield and smaller decreases (26 and 10 percent, respectively) when either treatment was performed separately. A third experiment consisted of four genotypes harvested at seven stages; the first harvest was at milk stage and the last stage was four months

later. The results indicated that the grain would have a higher proportion of protein than mature seed if the plant was killed by a frost when the seeds were in the milk stage. The percentage protein in the grain was not significantly affected by delaying harvest until winter. The fourth experiment involved growing eleven genotypes at three locations for two years and measuring grain yield, protein yield, and percentage protein. The results of this experiment suggest that genotypes should be evaluated at the location where they are intended to be grown because significant interaction of genotypes × locations × years indicated that the genotypes did not perform in the same manner at all locations in both years for the three characters.

The overall results of these experiments suggest that the performance of a genotype can best be measured by growing it at the location of intended utilization and by taking the seed sample from several fully developed, open pollinated heads. The environmental effects on percentage protein need to be further studied to determine the effects of different planting dates and population levels. The latter is presently under investigation. Furthermore, lysine should be studied under the conditions used in this study plus those suggested above.

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APPENDIX

APPENDIX

Appendix Table A1. Mean values of eight characters measured from 65 sorghum genotypes of the incomplete diallel grown in 1967.

Genotype	Date 50% Heading	Leaf No.	Height (cms)	Grain Yield (kg/ha)	% Protein	% Lysine	Protein Yield (kg/ha)	Lysine Yield (kg/ha)
0305	8-18	13.3	142.5	5697	12.53	1.66	711.3	11.82
MRT × 0305	8-10	13.5	176.3	7989	12.58	1.45	1005.7	14.62
CK60 × 0305	8-11	13.8	187.8	7515	11.93	1.53	893.7	13.73
WHT × 0305	8-9	11.8	166.3	8500	11.98	1.42	1017.2	14.51
RDL × 0305	8-10	13.0	163.8	9286	12.03	1.43	1118.5	15.85
0786	7-25	12.0	168.8	4326	15.53	1.26	690.1	7.66
MRT × 0786	7-20	10.0	165.0	5686	15.43	1.25	879.7	11.04
CK60 × 0786	7-21	12.0	175.0	6694	13.68	1.56	914.1	14.13
WHT × 0786	8-2	13.5	198.8	7776	14.30	1.42	1121.4	15.60
RDL × 0786	8-1	13.8	206.3	7902	14.00	1.38	1106.5	15.26
0819	8-5	14.5	176.3	6734	14.05	1.97	923.2	18.19
MRT × 0819	8-9	14.3	231.3	7166	14.25	1.61	1139.4	18.58
CK60 × 0819	8-8	13.0	240.0	7568	12.43	1.65	939.6	15.23
WHT × 0819	8-10	13.0	215.0	7588	13.05	1.67	967.0	15.75
RDL × 0819	8-10	13.3	242.5	7861	12.88	1.34	1012.0	11.29
1150	8-2	12.8	238.8	8143	11.23	1.99	915.3	17.91
MRT × 1150	7-26	12.3	233.8	7329	14.28	1.75	1041.6	18.23
CK60 × 1150	7-26	12.8	231.3	8765	12.58	1.67	1108.0	17.72
WHT × 1150	8-2	13.5	233.8	8919	12.83	1.56	1154.5	18.20
RDL × 1150	8-2	13.5	262.5	8952	13.38	1.74	1192.5	17.84
1360	7-29	10.5	250.0	5394	12.05	1.61	651.5	10.22
MRT × 1360	7-21	11.3	197.5	5366	15.28	1.42	817.3	11.51
CK60 × 1360	7-23	11.0	201.3	4838	13.20	1.38	649.5	9.22
WHT × 1360	7-25	12.5	183.8	7076	12.50	1.48	883.4	13.24
RDL × 1360	7-31	11.8	181.3	6389	13.35	1.54	854.7	13.16
1457	8-17	14.3	217.5	5290	11.78	1.55	625.0	9.77
MRT × 1457	8-2	10.8	205.0	7526	12.40	1.55	928.0	14.74
CK60 × 1457	8-3	13.0	216.3	6810	12.15	1.43	822.1	11.55

Appendix Table A1. (Continued)

Genotype	Date 50% Heading	Leaf No.	Height (cms)	Grain Yield (kg/ha)	% Protein	% Lysine	Protein Yield (kg/ha)	Lysine Yield (kg/ha)
WHT × 1457	8-6	13.0	205.0	7946	12.05	1.35	963.5	13.17
RDL × 1457	8-3	13.0	231.3	7747	12.08	1.64	934.4	15.00
1814	7-9	11.8	170.0	3592	13.45	1.63	485.2	7.76
MRT × 1814	7-12	9.8	161.3	5130	13.45	1.55	689.0	10.70
CK60 × 1814	7-13	8.8	191.3	6475	12.35	1.43	798.3	11.31
WHT × 1814	7-14	10.8	172.5	6763	12.18	1.49	841.9	12.17
RDL × 1814	7-17	11.8	186.3	7181	12.58	1.57	894.5	14.02
1884	8-7	12.3	152.5	5736	11.30	1.51	641.5	8.41
MRT × 1884	7-26	10.3	158.8	6922	11.48	1.68	796.0	13.70
CK60 × 1884	7-27	11.3	153.8	7756	10.23	1.69	792.2	13.39
WHT × 1884	7-31	11.3	152.5	7907	10.43	1.71	822.8	14.62
RDL × 1884	8-3	12.0	170.0	8197	10.65	1.71	874.2	14.69
2486	7-30	11.5	97.5	4410	13.18	1.65	573.9	10.00
MRT × 2486	7-21	9.8	128.8	7230	13.08	1.64	940.3	15.20
CK60 × 2486	7-21	10.5	141.3	7724	12.15	1.72	943.2	16.17
WHT × 2486	7-27	11.8	106.3	7085	12.03	1.67	852.3	14.33
RDL × 2486	7-25	10.8	141.3	7742	11.83	1.83	916.2	16.61
5075	8-19	10.5	267.5	3088	13.35	1.36	413.1	12.44
MRT × 5075	8-13	11.5	271.3	6698	14.60	1.45	974.4	13.87
CK60 × 5075	8-11	12.5	288.8	6975	13.18	1.70	919.3	15.76
WHT × 5075	8-10	12.5	265.0	6839	14.23	1.45	980.2	14.21
RDL × 5075	8-10	11.8	260.0	6470	13.80	1.72	894.0	15.30
5126	7-31	10.8	132.5	3832	14.93	1.47	575.3	10.37
MRT × 5126	7-20	10.0	128.8	4786	13.40	1.55	640.6	9.85
CK60 × 5126	7-21	11.3	136.3	5856	12.38	1.59	721.8	11.55
WHT × 5126	7-24	11.8	121.3	6517	12.45	1.58	816.4	10.67
RDL × 5126	7-27	11.3	136.3	6968	12.40	1.79	861.5	15.34
5217	7-30	11.0	166.3	5189	13.85	1.63	719.1	11.71
MRT × 5217	7-21	10.3	157.5	5791	12.55	1.45	723.5	10.82

Appendix Table A1 (Continued)

Genotype	Date 50% Heading	Leaf No.	Height (cms)	Grain Yield (kg/ha)	% Protein	% Lysine	Protein Yield (kg/ha)	Lysine Yield (kg/ha)
CK60 × 5217	7-20	10.0	180.0	6764	12.05	1.58	814.6	12.95
WHT × 5217	7-28	12.3	187.5	6756	12.75	1.29	862.2	11.41
RDL × 5217	7-25	11.5	196.3	7575	13.30	1.17	1009.3	11.82
Martin	7-23	10.3	92.5	4546	14.95	1.37	678.8	10.46
CK60	7-24	11.0	105.0	5081	11.33	1.66	574.5	9.24
Wheatland	7-31	11.5	82.5	5353	13.25	1.41	711.0	9.58
Redlan	8-3	11.3	110.0	5665	12.18	1.72	685.8	9.82
RS610	7-16	9.5	115.0	5469	12.35	1.52	675.6	11.80
LSD_{05}				1720.4	0.968	0.346	116.66	3.120
LSD_{01}				1905.7	1.273	0.454	153.32	4.101

Appendix Table A2. Means of six characters measured from the sorghum diallel of nine parents and 36 F_1 hybrids grown in 1968.

Genotype	Flowering†	Leaf No.	Height (cm)	L.A.I.†† (cm^2)	Head Exert. (cm)	Head Length (cm)
0355	31	14.0	348	191	22.7	34.6
0793	17	15.4	214	193	12.2	19.0
0819	26	16.1	271	118	11.8	13.4
1884	29	16.7	189	96	23.4	26.4
5187	13	11.0	83	143	12.5	23.5
Martin	10	10.7	140	151	25.3	26.8
CK60	10	11.2	136	124	16.1	23.2
Wheatland	19	12.4	109	175	15.2	27.0
Redlan	15	11.6	150	123	18.3	24.4
0355 × 0793	29	16.7	363	205	18.0	27.4
0355 × 0819	28	15.8	375	166	21.2	24.8
0355 × 1884	45	19.0	414	116	22.5	35.7
0355 × 5187	30	15.2	364	176	29.1	26.5
0355 × MRT	28	13.2	335	215	24.2	34.3
0355 × CK60	29	14.6	368	190	22.5	31.3
0355 × WHT	29	15.0	345	177	24.7	30.5
0355 × RDL	28	13.9	368	120	25.9	27.9
0793 × 0819	24	17.2	293	215	10.4	20.5
0793 × 1884	18	14.8	276	181	18.7	25.7
0793 × 5187	8	12.3	240	172	23.7	18.3
0793 × MRT	6	12.3	255	162	25.2	23.2
0793 × CK60	7	11.7	253	153	18.9	22.5
0793 × WHT	10	13.7	261	190	22.6	23.0
0793 × RDL	10	12.8	266	158	21.1	21.7
0819 × 1884	29	17.8	379	135	21.4	22.9
0819 × 5187	20	14.8	293	156	13.7	21.4
0819 × MRT	18	14.9	309	149	20.8	21.6
0819 × CK60	16	14.4	291	100	17.8	21.2
0819 × WHT	27	15.7	304	132	19.7	19.7

Appendix Table A2. (Continued)

Genotype	Flowering†	Leaf No.	Height (cm)	L.A.I.†† (cm^2)	Head Exert. (cm)	Head Length (cm)
0819 × RDL	20	15.1	321	129	16.4	20.1
1884 × 5187	19	13.2	170	149	11.7	29.5
1884 × MRT	12	12.5	210	174	26.9	30.5
1884 × CK60	13	12.6	204	129	16.7	31.3
1884 × WHT	24	13.8	190	168	18.3	29.8
1884 × RDL	19	13.1	213	145	19.1	32.2
5187 × MRT	13	10.5	126	158	20.3	25.8
5187 × CK60	12	10.6	111	157	14.7	25.5
5187 × WHT	14	10.7	108	174	17.5	26.3
5187 × RDL	15	10.7	119	132	15.6	24.0
MRT × CK60	8	10.9	181	151	22.9	25.7
MRT × WHT	12	11.3	126	195	20.2	28.0
MRT × RDL	9	10.6	144	155	22.2	25.5
CK60 × WHT	7	10.3	124	173	21.1	25.2
CK60 × RDL	10	10.6	143	118	18.5	22.9
WHT × RDL	11	11.1	134	171	16.8	23.3
RS610	5	10.3	141	154	19.5	25.3
LSD_{05}	3.0	1.1	23.0	38.9	4.6	3.2
LSD_{01}	4.2	1.6	32.5	55.1	6.5	4.6

†July 1 was used as the base date for flowering.

††Leaf Area Index of flag leaf only.

Appendix Table A3. Means† of seven characters measured from the sorghum diallel of nine parents and 36 F_1 hybrids grown in 1968.

Genotype	Grain Yield (kg/ha)	Yield/ Head (gm)	100 Seed Wt. (gm)	% Protein	Protein Yield (kg/ha)	% Lysine††	Lysine Yield (kg/ha)
0355	3143 q	16 n	1.20 u	17.35 a	545.9 m	2.04 f-m	11.1 l
0793	8497 c-g	50 f-h	3.71 a-c	13.45 c	1144.0 a-c	1.87 j-m	21.3 b-f
0819	6725 i-k	38 j	3.27 d-f	13.42 cd	900.0 e-h	2.64 ab	23.6 a-c
1884	7628 f-j	38 jk	2.44 l-p	10.13 m-p	771.2 g-k	2.74 a	21.2 b-f
5187	5455 k-o	28 lm	2.26 m-q	10.70 j-n	579.9 lm	2.20 d-j	12.6 i-l
Martin	6252 j-n	32 j-m	2.28 m-q	12.82 c-l	799.4 f-k	1.91 i-m	15.3 g-l
CK60	6403 j-n	33 j-l	2.44 l-p	10.45 k-o	666.1 i-m	2.45 a-e	16.6 g-j
Wheatland	7033 g-j	38 jk	2.58 k-l	10.42 k-o	731.9 h-l	2.21 d-j	16.2 g-j
Redlan	7168 g-j	38 jk	2.47 l-o	10.83 i-m	777.0 g-k	2.02 f-m	15.6 g-l
0355 × 0793	4248 o-q	22 mn	2.16 p-s	16.20 b	690.1 i-m	1.90 i-m	13.1 i-l
0355 × 0819	4917 l-p	25 l-n	2.23 o-r	16.07 b	790.3 g-k	1.88 j-m	14.9 g-l
0355 × 1884	4838 n-p	26 lm	1.27 u	16.42 b	794.9 g-k	1.92 i-m	15.3 g-l
0355 × 5187	4999 l-p	25 l-n	1.80 t	16.27 b	813.1 f-k	1.82 j-m	14.7 g-l
0355 × MRT	4225 o-q	26 lm	1.97 r-t	18.22	770.0 g-k	1.74 lm	13.4 g-l
0355 × CK60	5102 l-p	38 jk	1.89 s-t	16.22 b	826.5 f-j	1.78 k-m	14.7 h-l
0355 × WHT	3915 pq	24 l-n	2.07 q-t	16.70 ab	653.0 j-m	1.74 m	11.4 g-l
0355 × RDL	4739 n-p	31 j-m	2.15 p-s	16.25 b	769.5 g-k	1.74 m	13.4 h-l
0793 × 0819	15863	100	3.65 a-c	11.63 f-j	1841.0	2.11 l-k	38.9
0793 × 1884	10969 a	59 b-f	3.48 cd	10.75 j-n	1178.2 ab	2.18 d-j	25.7 ab
0793 × 5187	9985 a-c	51 d-h	3.86 ab	11.23 h-l	1117.8 a-d	1.98 g-m	22.2 b-e
0793 × MRT	9054 b-f	48 h-i	3.55 cd	11.92 l-h	1080.2 a-d	2.09 f-m	22.4 b-e
0793 × CK60	9634 a-d	49 g-i	3.62 a-c	10.77 j-n	1039.1 b-e	2.02 f-m	20.9 d-f
0793 × WHT	9361 b-l	56 c-h	3.62 a-c	10.45 k-o	980.6 c-f	2.30 c-h	22.7 b-d
0793 × RDL	10176 ab	59 b-f	3.88 a	11.45 g-k	1165.9 ab	2.16 d-j	25.2 a-c
0819 × 1884	12896	75 a	3.47 cd	11.98 e-h	1542.2	2.16 d-j	33.3
0819 × 5187	10049 ab	67 ab	3.58 b-c	11.88 e-h	1192.4 ab	2.15 d-j	25.7 ab
0819 × MRT	9686 a-d	59 b-g	3.18 e-g	12.80 c-l	1224.2 a	2.22 c-j	27.1 a
0819 × CK60	9279 b-l	53 c-h	3.42 de	11.95 e-h	1109.2 a-d	2.26 c-i	24.7 a-c

Appendix Table A3. (Continued)

Genotype	Grain Yield (kg/ha)	Yield/ Head (gm)	100 Seed Wt. (gm)	% Protein	Protein Yield (kg/ha)	% Lysine††	Lysine Yield (kg/ha)
0819 × WHT	9451 a-e	60 b-d	3.51 cd	12.32 e-g	1162.1 ab	1.94 h-m	22.5 b-d
0819 × RDL	10116 ab	62 bc	3.44 c-e	11.80 e-i	1192.0 ab	2.11 e-k	25.2 a-c
1884 × 5187	8022 e-i	50 f-h	2.63 j-k	9.33 op	748.6 h-l	2.48 a-d	18.5 d-h
1884 × MRT	8230 e-h	40 ij	2.81 h-k	10.30 l-o	848.4 f-j	2.07 f-m	17.5 f-i
1884 × CK60	9032 b-f	48 g-i	2.99 gh	9.50 op	857.4 f-i	2.56 a-c	21.8 b-f
1884 × WHT	9604 a-d	60 b-e	2.87 h-j	9.80 n-p	941.5 d-g	2.32 b-g	21.8 b-f
1884 × RDL	10369 ab	57 c-h	2.91 g-i	9.18 p	952.2 d-g	2.37 b-f	22.4 b-e
5187 × MRT	5820 k-n	30 j-m	2.99 gh	13.52 c	783.5 g-k	2.01 f-m	15.6 g-l
5187 × CK60	5311 k-p	33 j-l	2.55 k-m	11.85 e-h	621.1 k-m	1.98 g-m	12.3 j-l
5187 × WHT	6267 j-n	37 jk	2.79 h-k	11.33 g-k	709.7 h-m	2.10 e-m	14.8 g-l
5187 × RDL	6151 j-n	31 j-m	3.04 f-h	12.57 c-f	774.6 g-k	1.98 g-m	16.0 g-k
MRT × CK60	7228 g-j	39 ij	2.53 k-n	11.65 f-i	843.4 f-j	2.13 d-k	18.0 e-i
MRT × WHT	5949 k-n	33 j-l	2.40 l-p	12.20 e-h	725.8 h-m	1.93 h-m	13.8 g-l
MRT × RDL	6338 j-m	33 j-l	2.25 n-q	12.48 ef	787.1 g-k	1.98 g-m	15.5 g-l
CK60 × WHT	6136 j-n	33 j-l	2.38 l-p	11.40 g-k	700.9 h-m	1.95 g-m	13.6 h-l
CK60 × RDL	6798 h-j	37 jk	2.60 kl	11.18 h-l	764.3 g-l	1.95 g-m	15.0 g-l
WHT × RDL	6452 j-l	34 j-l	2.34 l-q	10.57 k-n	681.3 i-m	2.01 f-m	13.7 h-l
RS610	6595	34	2.33	10.98	723.5	2.18	16.0

†Duncan's new multiple range test was used to compare means; any two means followed by the same letter are not significantly different at the .05 level; any two means not followed by the same letter, or any letter, are significantly different at the .05 level.

††Percentage lysine as a proportion of protein.

Appendix Table A4. Mean squares of the analyses of variance of Wr-Vr values from 13 characters of the nine parent diallel grown in 1968.

Character	Mean Squares†		
	Blocks	Entries	Error
Flowering	280.11 **	495.18 **	19.61
Leaf Number	4.38 **	2.34 **	0.39
Height	1090	16363 **	1368
L.A.I.	9000 *	6030	2597
Head Exertion	679.91	463.98	326.01
Head Length	187.22	126.49	142.28
Grain Yield	8890	7993	10339
Head Yield	20100 **	55343 **	2954
100 Seed Wt.	0.0059*	0.0035	0.0016
% Protein	0.0882	1.0349**	0.1461
Protein Yield	4069	6952 **	3449
% Lysine	0.0041*	0.0010	0.0010
Lysine Yield	21.61	36.61 **	9.30

*Significant at the .05 level.
**Significant at the .01 level.
†Blocks, entries, and error have 3, 8, and 24 degrees of freedom, respectively.

Appendix Table A5. Means for grain yield, protein yield, percentage protein, and 100 seed weight of five varieties subjected to four bagging treatments which were carried out in 1967 and 1968.

Variety	Treatment	Grain Yield (kg/ha)			Protein Yield (kg/ha)			% Protein			100 Seed Weight (gms)		
		1967	1968	Mean	1967	1968	Mean	1967	1968	Mean	1967	1968	Mean
RS610	1	5612	7023	6318	392	401	397	11.88	10.80	11.34	2.30	2.33	2.32
	2	4818	6006	5412	339	352	346	11.96	11.06	11.51	2.23	2.38	2.31
	3	4103	3876	3990	311	250	281	12.93	12.16	12.55	2.55	2.52	2.54
	4	4416	3633	4025	347	237	292	13.19	12.23	12.71	2.55	2.24	2.40
0819	1	6627	7467	7047	562	385	474	14.42	12.26	13.34	3.18	3.27	3.23
	2	5296	8646	6971	438	458	448	14.07	12.07	13.07	3.15	3.23	3.19
	3	4780	7106	5943	417	400	408	14.90	12.19	13.55	3.33	3.24	3.29
	4	5305	7673	6489	386	451	419	14.58	12.20	13.39	3.28	3.27	3.28
Redlan × 0819	1	9991	11231	10611	718	528	623	12.14	11.13	11.64	2.95	3.44	3.20
	2	8905	9501	9203	639	461	550	12.24	11.25	11.75	3.08	3.54	3.31
	3	9291	8709	9000	675	440	558	12.28	11.43	11.86	3.10	3.44	3.27
	4	5293	7703	6498	389	400	394	12.47	10.79	11.63	3.20	3.19	3.20
1884	1	6505	8470	7488	403	548	475	10.55	9.71	10.13	2.45	2.44	2.45
	2	6783	7609	7196	403	486	444	10.13	9.96	10.05	2.43	2.44	2.44
	3	5353	4457	4905	332	288	310	10.57	10.59	10.58	2.73	2.73	2.73
	4	5126	4915	5021	298	317	308	9.91	11.09	10.50	2.70	2.75	2.73
Redlan × 1884	1	9262	11512	10387	544	681	613	9.99	8.87	9.43	2.75	2.91	2.83
	2	8956	8946	8951	519	538	529	9.85	9.14	9.50	2.73	2.92	2.83
	3	7066	7465	7266	438	453	446	10.57	9.52	10.05	2.68	2.80	2.74
	4	6026	6565	6300	398	374	386	11.23	9.83	10.53	2.75	2.81	2.78

Appendix Table A6. Means of percentage protein of four sorghum genotypes harvested at seven stages of maturity in 1967.

Genotypes	Harvest Stage	% Protein Mean
RS610	1	13.29
	2	12.20
	3	11.90
	4	11.93
	5	11.95
	6	12.32
	7	12.30
AKS614	1	13.70
	2	12.21
	3	12.16
	4	12.55
	5	12.26
	6	12.14
	7	12.16
0819	1	14.20
	2	13.71
	3	13.53
	4	13.95
	5	14.43
	6	14.14
	7	14.62
1884	1	12.90
	2	11.85
	3	11.20
	4	10.71
	5	10.13
	6	10.38
	7	10.50

VITA

VITA

Frederick Clinton Collins was born May 31, 1941, at Prairie Grove, Arkansas, to Mr. and Mrs. Edgar Collins, and he was reared on a farm near Lincoln, Arkansas. He received his elementary and secondary education from the Lincoln schools.

He enlisted in the Arkansas Army National Guard in 1957 and received an honorable discharge in 1965. In the fall of 1959 he enrolled in the University of Arkansas and worked for the Agronomy Department three and one-half years as an undergraduate. He earned his B.S.A. degree in 1963 and began his graduate studies under Dr. R. L. Thurman. His M.S. thesis was on the inheritance of crown rust resistance in oats. In 1964 he moved to Colorado State University to work as a geneticist for U.S.D.A. Sugarbeet Investigations under Dr. LeRoy Powers. He completed the requirements for the M.S. degree there and the degree was granted by the University of Arkansas in 1965. After Dr. Powers passed away in 1965, Mr. Collins applied for and was granted an assistantship from Purdue University to work under Dr. R. C. Pickett on the A.I.D. sponsored project to improve the nutritional quality of sorghum.

He and his wife, the former Jo Anna Sheffield, were married in 1961. He is a member of Alpha Zeta, Gamma Sigma Delta, Sigma Xi, American Society of Agronomy, and Crop Science Society of America.