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A Thesis

Submitted to the Faculty

of

Purdue University

by

Greg Otto Hinze

In Partial Fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

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ABSTRACT

Hinze, Greg Otto. Ph.D., Purdue University, May 1973. Relationship of Factors Influencing Protein Yield and Quality in Sorghum bicolor (Linn.) Moench. Major Professor: J. D. Axtell.

A total of 19 lines from the world collection of sorghum were used as male parents in crosses with four cytoplasmic male sterile lines to produce a total of 76 hybrids. The males were selected for phenotypic diversity of leaf angle, leaf area, plant height, and maturity. The male sterile lines used were Redlan, Martin, Combine Kafir-60, and KS-24 All material involved in this study was grown at Lafayette, Indiana in 1969.

Analyses for combining ability effects were determined for the following characters: early vigor, days to 50% bloom, number of leaves, flag-leaf area, third-leaf area, tillering, stalk size, relative canopy, leaf angle, lodging, plant height, percent protein, percent lysine, head length, yield of grain per head, weight of 100 grains, grain yield per acre, mg protein per seed, and mg lysine per seed. Highly significant mean squares were determined for male effects for all characters. Female effects were significant or highly significant for days to 50% bloom, plant height, head length, mg of protein per seed, and mg of lysine per seed. Significant male or female effects were considered expressions of additive gene action, which could be utilized in varietal improvement. Specific combining ability, indicated by significant mean square estimates of male × female interactions, would indicate effects

best exploited in a hybrid production scheme. Significant or highly significant interaction levels were determined for early vigor, days to 50% bloom, leaf number, flag-and third-leaf areas, relative canopy, leaf angle, lodging, plant height, percent lysine, head length, grain yield per head, and mg protein per seed.

In this study male sterile KS-24 was found to be a generally superior female parent for protein quantity and quality. Its hybrids averaged highest in yield, highest in percent lysine and mg lysine per seed, and second in percent protein and mg protein per seed. In addition, its hybrids were early in maturity and averaged 20 cm shorter in plant height than hybrids of the other three male sterile lines.

This study indicated a positive and significant correlation of mg protein per seed with seed weight, percent protein, and mg lysine per seed, and was not correlated with grain yield. A selection program utilizing mg protein per seed appeared to offer a powerful index to improve the protein selection program without reducing yield, especially if it were combined with a screening test for high levels of percent lysine.

Seed weight was correlated with plant height, but not with yield per acre. Protein content per seed remained relatively constant over yield per acre. These factors indicated no adverse effects should develop relating to yield if a selection program emphasized seed size.

Plant height was correlated with grain per head, 100 grain weight, grain yield, percent protein, and protein and lysine per seed. Unfortunately tallness was also correlated with percent lodging and negatively correlated with percent lysine.

Correlation coefficients between parental performance and F_1 performance for six quality factors were calculated. In a few instances these were determined to be significantly correlated. However these correlations were deemed useful only if a full testing program was impossible since the confidence interval established for these values is too wide to allow utilization as a reliable indicator.

INTRODUCTION

Present day plant breeding is often directed toward the nutritional improvement of a crop as much as yield per se. The genetic potential of material often is obscure, awaiting the discovery of significance. The unknown qualities present in diverse genotypes of any species, and the inability to predict future requirements, has encouraged the assembly of genetic stocks. The first significant step in a world-wide concentrated sorghum improvement program was the collection of germplasm. Although the exact number of lines in the world collection is unknown, probably over 15,000 are included. This represents an overwhelming number to the sorghum breeder attempting to utilize the wealth of germplasm stored therein. Information is needed which could be used by sorghum improvement programs, indicating the potential usefulness of the collection and its sources or concentrations of genetic material.

This study was undertaken to provide guidelines for selection of parental lines. Lines to be evaluated as males were selected from world collection entries growing at Lafayette, Indiana in 1967. Efforts were directed toward obtaining different races of sorghum and a diversity of morphological plant characters with respect to head length, plant height, and leaf size and angle. It was felt that some trait might be located which would indicate which race or which plant type might possess unique characteristics of value to an improvement program.

The objectives of this study were:

1. To evaluate representatives of the world collection as male parents in F_1 combinations for grain yield and other agronomic factors.

2. To evaluate the female (male-sterile) lines available for use in general and specific combining ability effects upon their F_1 grain yield, and protein and lysine contents.

3. To measure the effect and association of leaf, stem, and grain characters upon the yields of these sorghum hybrids.

4. To determine the extent that parental performance could be used to predict F_1 performance for grain yield and grain quality factors.

5. To examine the potential of establishing an improvement program based on the evaluation of absolute protein and lysine per

REVIEW OF LITERATURE

The world collection of sorghum (Sorghum bicolor (Linn.) Moench) has grown to include many thousands of entries. Estimates vary widely, ranging from 4,500 to over 12,000 accenssions (4, 55, 67, 68). It is probable that the size of the collection has grown considerably since the lower counts were reported, although the lower counts may also have eliminated much of the duplication of material which inevitably exists. The large number of lines in the sorghum collection offer much readily available germplasm to the sorghum breeder. Maunder (50) has pointed out the difficulty of efficiently evaluating this great quantity of material in addition to conducting regular breeding projects.

Limited Genetic Base of the Domestic Sorghum Crop

Martin (49) in 1936 estimated that the sorghum crop in the United States traced to 20 sorgo introductions, 3 kafirs, 2 durras, and 1 each of milo, shallu, feterita, and hegari. Each of these is a specific type of sorghums. Maunder (50) traced those introductions to six African and Asian centers of diversity as designated by Vavilov (82). The present crop of sorghum now grown represents many more lines according to Maunder, but the lines developed from the original introductions did represent a narrow genetic base. It is this material which has provided most of the commercially important male-sterile (often termed A-line) lines used in the present production of sorghum hybrids. King et.al. (41) reported

less genetic diversity for combining ability among A-lines than among R-lines (those which restore fertility to the F_1 hybrid).

Rosenow (68) indicates that sorghum varieties and hybrids now grown in the United States represent a small fraction of those known in the world. Much of the total genetic diversity within the sorghum species is not being utilized at the present time in breeding and improvement programs in this country. Many of the alien sorghums are too tall, fail to mature, or are otherwise unadapted to conditions in the United States. It is generally assumed that these alien lines possess many genes which could contribute substantially to yield, to insect and disease resistance, or to other quality aspects of American hybrids.

Importance of Genetic Diversity in Crop Improvement

Much research has indicated the value of diverse germplasm in the improvement of crops to suit man's requirements. Vavilov (82) found that the history of breeding clearly shows that the great achievements of the past resulted from the use of material introduced from distant regions. Improvement due to exotic lines was especially evident in Canada, Australia, Argentina, South Africa, and the United States. Sweden greatly improved the local wheat varieties by crossing them with English squareheads.

Harlan and Martini (28) pointed out that the plant breeder is helpless in redesigning plants without living materials of diverse character. A single strain of no commercial value may furnish a required trait. For instance, the barley variety Lion had been the source of smooth awn in barley for every smooth-awned variety grown in North America to 1936. Since a particular trait may be unique to a single variety, a large

collection is a necessity. In barley, for example, an Egyptian variety of no value per se had been a valuable parent; Ethiopian material had proven to have resistance to covered smut and summer cold; a Japanese line provided smut resistance; and a variety from Turkestan had an escape mechanism to cold killing of flowers.

Contemporary wheat breeders have a vast array of material with which to work. Clark (16) indicated that Vavilov in a personal communication stated that the Russians had assembled a collection of not less than 31,000 types by 1935. A potential use for this type of collection was shown by McFadden of South Dakota who crossed Marquis wheat with Yaroslav emmer to obtain the very important spring wheat varieties Hope and H-44.

By 1936 Stanton (75) was also pointing out the importance of diversity of germplasm and the wealth of it available for improving the oats program in the United States. Never before had there been such a wealth of superior germplasm awaiting the exploitation of the plant breeder. Victoria oats, a selection out of South Africa, was not of commercial value per se but did provide the necessary sources of resistance to many races of crown rust and smut (3).

A tetraploid oat found in a collection of oats from the Mediterranean region was discovered to have large caropses, high protein, outstanding resistance to crown rust, and thick culm walls (54). The hexaploid oat, Avena sterilis, has been found to possess resistance to the major oat diseases here in the U. S.

Hayes and Johnson (29), Wu (88), and Johnson and Hayes (38) were among the first to report that diversity of genetic origin was an important factor in obtaining maximum heterosis of F_1 corn hybrids. Wu reported that a better F_1 can be expected, on the average, if the parental inbreds are

combined in such a manner that lines of diverse genetic origin are united. Hayes and Johnson reported similar results, finding that 65% of the hybrids resulting from crosses involving unrelated parents gave yields equal to those of adapted, high-yielding hybrids. This was higher than the proportion of superior crosses obtained when the parent lines possessed some degree of relationship. They also considered combining ability to be an inherited characteristic. In their later paper (38) they found that combining low-yielding inbreds (low x low) did not produce a superior hybrid, even though diverse germplasm was involved. Crosses of low x high, and high x high were found to be about equal. Grafius et.al. (23) reported that the work of Suneson and Riddle, Harlan, et.al., and Immer, with barley showed that high-yielding parents tended to produce high-yielding hybrids.

Soybean varieties presently adapted to the North Central region of the United States have been estimated by Johnson and Bernard (37) to trace to six different introductions of Manchurian origin. They estimate that intense selection among and within these lines may have reduced genetic variability to such a low level that further improvement is difficult. Thorne and Fehr (80) studied high-protein exotic parents in crosses with adapted lines in an effort to upgrade the protein, oil, and protein plus oil contents of soybeans. They found the high-protein content of the exotic strains to transmit readily to their offspring, and selection of high-yielding, high-protein strains from crosses in which exotic strains were involved was possible. The exotics were used to establish populations in both 2-way [adapted line x exotic] and 3-way [(adapted x exotic) x (adapted)] crosses in this study. Population means were calculated to have been determined largely by additive effects, but some epistatic

effects were found. Population means were predictable from parental performance.

The predictive performance of the parental lines is of interest since Harlan (27) has pointed out that the value of exotic germplasm may not be generally realized until these varieties are studied as parents. In well established crops in the United States, most plant introductions will not perform as well as well adapted varieties, according to Harlan. As parents, these introductions may have outstanding qualities which would not be apparent from their performance as pure varieties. Harlan points out that the plant breeder needs to view the exotic lines as introduction of genes, not as lines. Allard (3) also indicated that the role of plant introductions in the future will probably be less in providing varieties directly, as they once did, but rather in providing a reservoir of germplasm. Since some of the world collections contain tens of thousands of accessions, the task of exploring each accession for intrinsic parental value becomes formidable.

In sorghum, Niehaus and Pickett (56) found striking heterosis in a population of sorghum only if one parent was an introduction. This heterosis may have been due to either genetic diversity *per se* or to vigor associated with height and maturity genes. The value of introduced or exotic sorghum lines was also shown by Malm (47), who found new lines to have outstanding general combining ability with striking heterosis for yield, protein, and other traits. Genetic diversity appeared to be essential in obtaining hybrid vigor. Malm noted that selection for seed size or head size was more effective in improving yields than selection for seedling vigor.

Jakushevskii (33) found crosses between *Sorghum caffrorum* and

S. durra to be best for the region of Russia. His best crosses produced up to a 100% increase in grain yield.

King et. al. (41) reported in sorghum that R-lines with greater general combining ability (GCA) tended to produce high-yielding F_1 crosses regardless of the A-line.

Murty (55) evaluated genotype-environmental interactions of material at three locations in India. He found early vigor to be the most consistent, while flowering time and height were the most variable. The best groups for early vigor, which he felt also served to index drought resistance, were several Caudatum combinations, Zerazera, Roxburghii, Nervosum, and Nigricans-Guineense. The Durra, Shallu, Conspicuum, Cernuum, Subglabrascens, and Caudatum types were found to interact with environment for flowering time, whereas the Feterita, Hegari, Kafir, Zerazera, Rada, and Darso groups were stable. Considering all factors, Caudatum and Bicolor combinations appeared to interact most with environment

Sorghum Characters Studied

A review of the literature pertaining to the characters studies in this thesis follows.

Vegetative Characters

Early vigor, according to Murty (55), indicates the ability of a plant to establish well and is associated with drouth resistance. Grassy sorghum types were poor for this characteristic. Vigorous types were found concentrated in Nervosum and its combinations, Bicolor-Kafir, Caffrorum, Caffrorum-Birdp[illegible]f, Caffrorum-Durra, Nigricans, Nigricans-Bicolor, Nigricans-Guineense, Zerazera, and Caudatum-Nigricans. Early vigor was not necessarily associated with maturity. In the normal commercial sorghums,

outstanding vigor was found in Shallu, Hegari, Feterita, Sorgo, and S. almum.

Little information pertaining to agronomic crops is available to support Murty's contention that early vigor is associated with drouth resistance. Delouche (8) indicates that there are many reports of the influence of seed size on growth and development of plants in the horticultural field. In general, larger seeds in vegetable crops are higher in germination, vigor, and potential yield. Large seeds screened from a lot of Bragg variety of soybeans were found to produce distinctly superior plants with higher seed yield than did small seeds taken from the same lot.

In Colorado it was found that initial moisture content of the planted seed influenced the rapidity of germination and subsequent vigor of the emerging sorghum seedling (58, 89). Under the relatively hostile climate of eastern Colorado dryland culture, plants established by the more vigorous high-moisture seedlings yielded more grain than those plants from the lower moisture seeds. The advantages of early and vigorous germination were not as apparent under the irrigation practiced at a second test site. It would appear from these results that plants established from more vigorous seedlings tolerated drouth better.

Large-seeded populations of smooth bromegrass (Bromus inermis) were found to produce superior seedlings (81). The large-seeded selections imparted superior emergence capability to their seedlings, and greater weight per seedling and per unit area. This early vigor was apparently operative only during the seedling stage since mature plant characteristics did not reflect the superior seedling attributes. No observations of drouth response are noted.

Malm (47) found that large-seeded exotic lines tended to produce

high-yielding hybrids, while according to Quinby (60), sorghum hybrids appear to have a superior rate of growth which begins in the embryo and climaxs in a larger panicle on the hybrid. Neither author relates his results to drouth resistance.

If large seed is desired in sorghum to achieve seedling vigor, as indicated by the preceding material, size can be obtained. Voigt, et.al. (83) found three or four genetic factors involved in a cross of a selectio called Big Seed x Norghum. Additive effects predominated for size, and heritability was estimated at 60%. However Malm (47) found that parents selected for seeding vigor exhibited the lowest degree of general combining ability for grain yield, and Quinby and Schertz (67) and Blum (8) point out the negative correlation between seed size and seed number in sorghum.

Days to 50-percent flowering was determined to contribute substantially to genetic diversity in India by Murty (55). The wide range of variability which exists within groups may indicate the need of further categorizing the lines into maturity sub-groups, although it would be difficult due to photoperiod effects. Guineense, Margaritiferum, Nervosum and its combinations, Bicolor-Kafir, Dochna and its combinations, and Caffrorum and its combinations were found to flower in 60 to 70 days. The Roxburghii, Conspicuum, Membranaceum, Bicolor, Nigricans, Dobbs, some Caudatum combinations, Zerazera, and Durra and its combinations flowered in 70 to 80 days. Subglabrascens, Durra-Nigricans, and Nandyal, as well as some Caudatums, Roxburghii, Guineense, Subglabrascens and Nigricans were very late (over 80 days). Group variances for days to 50-percent flowering were highly heterogeneous.

Duration of growth and ultimate plant size in sorghum, with its

terminal inflorescence, are dependent upon the time at which floral initiation occurs. Delaying floral initiation results in a plant with a thicker stem, a larger number of nodes and leaves, and obviously delays flowering and maturity according to Quinby (61).

Quinby and Schertz (67) report that plant size is a reflection of duration of growth within the milo group. The effect of maturity genes on plant size can be seen in milo varieties having the same genetic background and the same height genotype. Since duration of growth depends on time of floral initiation, which is in turn controlled by a few genes with major effects, plant size is likewise determined. If floral initiation occurs quickly, the sorghum plant will have few leaves and be relatively small. Delaying floral initiation will result in a larger plant with more leaves. Sinnott (72) stated that the size of any organ depends on the size of the growing point. Abbe et.al. (1) showed that the relative size of a leaf of Zea mays is determined at the time the leaf primordium is laid down. Assuming that sorghum has the same type of growth, the relative increase in the size of sorghum leaves toward the top of the plant must result from the greater circumference of the growing point as it matures. If a growing point increases in size with time, a head differentiating from an older growing point should be larger than from a growing point differentiating earlier. The predominant factor in both time of maturity and plant size is the duration of growth of the meristem prior to floral initiation (67).

The relationship between duration of growth and plant size was recognized when the first three maturity genes were determined in milo. The table below shows the effect of the regression of yield on days to flower. The varieties used were two dwarfs of similar background.

Table 1. The influence of days to floral initiation on leaf number and plant size of three milo maturity genotypes from a June 20, 1944 planting at Chillicothe, Texas.

Criteria	Genotype		
	Early $ma_1Ma_2ma_3Ma_4$	Intermediate $Ma_1ma_2ma_3Ma_4$	Ultralate $Ma_1Ma_2ma_3Ma_4$
Number of days to anthesis	49	69	102
Number of leaves	16	22	32
Height of plant, cm	86	88	152
Length of longest leaf, cm	51	65	78
Diameter of stalk, cm	1.4	2.3	2.5
Weight of heads, gm	109	163	122
Weight of plant, gm	195	281	440

Source: Quinby and Karper (64)

The table illustrates that duration of growth is positively associated with plant size, best illustrated by total weight of the plant. Difference in size is apparently the result of duration of growth alone and not to a difference in rate of growth. A high positive correlation exists between total weight of plant and grain yield if growing conditions remain favorable. This association of low yields with short duration of growth exists in the tropics as well as in temperate zones. The wise choice is to grow the latest variety that will mature without encountering unfavorable weather conditions or insect or disease damage (67).

Sorghums are short-day plants, since maturity is hastened by shorter days (61). For example, all strains of milo are sensitive to short photoperiod and cannot be distinguished by maturity from each other under 10-hour days. Quinby and Schertz (67) state that differences in maturity are due to differential response by varieties to factors of photoperiod and temperature. These responses to photoperiod are controlled by four gene loci with an allelic series at each locus.

The maturity genotypes of some varieties are known (61). In these

varieties, combinations of dominants and recessives at the four gene loci result in maturities ranging from 40 to 90 days under growing conditions in Texas.

Most tropical varieties need the long nights of the tropics to induce flowering. For this reason many varieties in the world collection cannot be used in the temperate zones in their present maturity forms. Most tropical varieties studied have proven to be dominant at the first maturity locus, whereas most sorghums adapted to the temperate zones are recessive at the first locus. To be useful in the sorghum breeding programs of the temperate zones, these tropical types must be converted to maturity types of the adapted varieties (67).

Plant height variability was substantial and indicated considerable genotype-environment interaction due to its association with flowering time in the Indian collection studied by Murty (55). Among the three height classes of tall, medium, and short, the shorts constituted 31.5% of the collection. Subseries Caffra, Nervosa, and Durra had the highest concentration of short lines, but within-group variation was large. Dwarfing genes were found to be mostly concentrated in Roxburghii-Shallu, Dochna-Kafir, Caffrorum, Caffrorum-Darson, Caffrorum-Birdproof, Caffrorum-Roxburghii, Caffrorum-Feterita, Caffrorum-Durra, Dobbs, Caudatum, Caudatum-Kaura, Caudatum-Kafir, Zerazera, Durra-Kafir, Durra-Nigricans, and Subglabrascens-Milo. Very tall types were found in Roxburghii, Conspicuum, and Durra. Medium height selections were found concentrated in Dochna, Nigricans, and Caudatum.

The effect of height on yield of sorghum, particularly grain yield, has intrigued many investigators. Graham and Lessman (24) evaluated height effects in Indiana by using reciprocal crosses between 3-dwarf and

2-dwarf lines of grain sorghum differing only at the Dw_2 locus (isogenic). Light availability data indicated that the taller 2-dwarf parents and F_1's were more efficient in utilization of available light, due to the spatial arrangement of leaves on the taller plants.

According to Loomis and Williams (44), the short-internode type of grain sorghum plant, which frequently has its relatively wide leaves very close together in relation to leaf width, is at a disadvantage. Better leaf canopy structure would result if leaf widths were reduced or if the leaf arrangement were more whorled to reduce the contiguous distribution resulting from the opposite and alternate arrangement. More efficient light utilization is achieved by illuminating many leaves at a modest level of light than by exposing a few leaves to full sun. In addition, the sheaths, petioles, and inflorescence parts may contain appreciable chlorophyll, and thus be productive structures.

King et.al. (41) point out that some of the best potential parents are not useful because their hybrids are too tall for present standards of grain sorghum. They also indicate the complex nature of lodging since F_1 hybrids seldom lodge under proper irrigation, but will lodge on dry-land or under irrigation if soil moisture becomes exhausted. This is especially true if both plant population and yield are high.

The first major improvement in grain sorghum varieties in the U. S. was the development of extra-dwarf, stiff-stalked combine types according to Webster (84). Beaver was the first of these types, and it was released in 1928. Wheatland, Day, and Colby varieties followed shortly thereafter. Height thus became of great concern to the sorghum breeder. The early literature reported that one of the manifestations of sorghum hybridization was the vigor as expressed in increased plant height.

Many of the observed cases, credited to heterosis, were probably due to the additive effects of complementary alleles for height as elucidated by Quinby (60).

Jastrebov (34) of Russia indicates that heterosis in sorghum hybrids in the F_1 is most frequently shown as an increase in height of the F_1. This has been reported by many American investigators (6, 42, 65, 66, 76). Quinby (60) found that one F_1 hybrid, Texas 601, which showed less heterosis for plant height and for certain other factors, was also the lowest yielding hybrid. RS 630, which showed 19% increase in plant height, was the most productive. Kirby and Atkins (42) and Liang (43) found significant average heterosis for nature plant height in the 24 F_1 populations of grain sorghum which they studied.

Quinby (62) reported that male-sterile cytoplasm contributed an average of three centimeters to total plant height as well as delaying flowering by one-half day. However, tillering, leaf width of the largest (fourth) leaf, and grain yield were not affected by the male-sterile cytoplasm.

Plant height was found to have the highest estimates of heritabilities of the various factors considered by Ali-Khan and Weibel (2). They concluded that individual plant selection in an F_2 population would be effective for plant height and days to flowering, but less effective for other characters.

Schertz (70) used an interesting and novel approach to evaluate the effect of a single gene for height. Short, doubled haploids recessive at all four major height loci were compared with tall, mutant derivatives which were recessive at three loci and dominant at the fourth. His comparison thus involved isogenic lines and compared 4-dwarf and 3-dwarf lines.

The lines differed not only in height but also in leaf-blade length, leaf-sheath length, panicle width, and grain yield. Schertz was unable to determine whether these other differences were due to the direct effect of the dominant height gene or to secondary effects of the height of the plants.

Campbell and Casady (12) also used isogenic lines to compare culm elongation rates of sorghum. They used isogenic lines of Japanese dwarf broomcorn, which differed only at the Dw_3 locus. Culm elongation proceeded slowly until 36 to 39 days after seedling emergence, but then proceeded rapidly until near anthesis. The line with dominant Dw_3 had a more rapid and extensive internode elongation than did the line with recessive dw_3.

Hybrids differing at the Dw_2 allele were compared by Maunder and Weddige (51). They found the 3-dwarf x 3-dwarf (3x3) hybrid to always be superior in grain yield to the 4x3, the 3x4, and 4x4 crosses under the 40-inch row width used. Yields of the shorter hybrids ranged from 92% to 95% of the 3x3 crosses. They felt that the decreased stalk breakage, decreased plant height, and apparent greater resistance to charcoal rot were of sufficient importance as to render the 5-8% yield reduction less significant.

Casady (13) compared populations of grain sorghums which could be considered isogenic, differing only in dominance or recessiveness for the dwarfing gene dw_3. He found the lines to differ not only in height but in yield and the two yield components, number of heads per plant and kernel weight. The height classes differed within varieties for number of kernels per head. Significant environment-by-height interactions for yield and several of its components indicated that environments had a differential effect on the height classes. Hadley et.al. (26) had results from

a similar experiment which essentially duplicates Casady's results. Hadley suggests that we need information to show whether the dwarf type plant might be superior to the tall type in areas of high light intensity and low humidity but inferior in areas of low light intensity and high humidity The relative value of the short genotype, in terms of harvesting ease and reduced lodging, needs to be compared to the 17% to 18% reduction in yield obtained.

The difficulty of firmly establishing yield parameters for the different height classes of sorghum was shown by Stickler and Younis (79). They used isogenic lines differing only at the Dw_3 locus. Their tall and short types averaged 57 and 37 inches at maturity. Row widths of 20 and 40 inches were used. Little evidence existed for a row width-by-plant height interaction, but plant height-by-stand density and plant height-by-variety interactions were significant in each trial. The short genotypes (dw_3) performed better at the high stand density of 120 square inches per plant, whereas the taller (Dw_3) genotype was superior at a lower stand density of 240 or 360 square inches per plant. Redlan was the chief contributor to the plant height-by-variety interaction for yield and components of yield, and was the latest variety used.

Effect of plant height competition. Considerable work pertaining to row width and plant population has been accomplished in grain sorghum (10, 25, 48, 59, 77), but little data regarding evaluation of competition effects between the different height genotypes generally found in sorghum testing programs. Ross (69) pointed out that multiple row plots were used to eliminate border row effects in the past. These border rows also provided material with which to study post-harvest lodging, provided an extra seed source, or extra plants for various tests. A more recent trend has

been to limit grain sorghum yield tests to material of similar growth habit. Often material to be tested is of limited seed supply, or land, labor, or facility limitations may impose restrictions.

Miller and Collier (52) compared 3x3, 3x4, and 4x4 dwarf hybrids of identical maturity under competitive conditions in Texas. The 3x4 hybrid produced 10.4% more grain when bordered by the 4x4 than when self-bordered, close to that observed in wheat by Jensen and Federer (35). Grain yield of the 4x4 hybrid was reduced by 4.8% when grown between the 3x3 hybrid. This figure again corresponds closely in magnitude to that observed in wheat by Jensen and Federer. Miller and Collier also found that the 4x4 hybrid, when grown between either of the taller hybrids, produced lower seed and test weights and a higher proportion of smaller seed than when grown in solid stands. Row width and plant height data are not available in the reference.

Kern and Atkins (40) conducted a similar test in Iowa. They compared 3x3 and 4x3 dwarf grain sorghum hybrids under conditions of self-border and counterpart border. Row spacings of 76 and 102 cm (30 and 40 in) were used. The 3x3 hybrid averaged approximately 133 cm (52 in) in height for the two years, the 4x3 about 112 cm (44 in). They state that the height differences for the entire experiment ranged from 17 cm (7 in) to 22 cm (9 in), with an average of 20 cm. Their results indicate that yields of the taller 3x3 were enhanced approximately 4% when bordered by the 4x3, whereas the yield of the shorter line was depressed about 3% due to being bordered by the taller line. The total divergence was thus about 7% when grown in mixed yield trials. According to their results, a 1 cm difference in height between the center row and the border row changed the center row yield about 0.2%.

Yields and other agronomic characteristics of four silage sorghum hybrids were compared by Johnson (36). These four hybrids were selected to cover a range of heights. Johnson designated these as short (up to 150 cm), short intermediate (to 190 cm), tall intermediate (to 230 cm), and tall (above 230 cm). Each type was grown in competition with itself and the other three heights. Silage yields of all types were greatest when bordered by the short type and lowest when bordered by the tall type. It was possible to group the two intermediate types into a single group from an analysis of their effects. Yields of the short type were decreased approximately 15% when grown adjacent to either of the intermediate types and by 30% when bordered by the tall genotype. Conversely, yields of the tall type were increased by about 11% next to the intermediates and by 14% when bordered by the short genotype. Johnson concluded that each of the three groups (short, intermediate, and tall) could be tested in single-rowed plots only if grouped by height classes.

Kern and Atkins (40) found significant differences in one experiment for border row effects on days-to-midbloom, plant height, and heads per plant. They felt however, that these effects were small when averaged over their three experiments. Johnson (36) found no border row effects on number of days-to-bloom or days in bloom, plant height, or lodging. He did find that the short and short intermediate classes had a slightly higher percentage of leaves and a lower percentage of heads when bordered by the tall genotype. The 3x4 hybrid in Miller and Collier's (52) experiment produced more heads with fewer small seed when bordered by the 4x4 hybrid. The 4x4, when bordered by the taller 3x4, produced lighter seed and a higher proportion of small seeds than its control.

Border row effects, as measured by most investigations, have been

shown in the literature to have profound influence especially on plot yields. If, as Donald (19) suggests, the plant type most desired is in fact the least competitive, the testing program must completely free the plots from intervarietal competition. It would appear that any plant improvement program which utilizes material of diverse type, especially height, will have to exercise great care in the yield evaluation of this material. The significant effect of even a relatively small difference in height, maturity, or type on a neighboring cultivar has to alert all experimenters, especially where relative yield differences are not large when based on solid-stand performance. The sorghum breeder has perhaps greater diversity of germplasm available than any other plant breeder. Almost all of it is interfertile. As a consequence he must work and must properly evaluate yield levels of material which vary widely in many important aspects. Large plots, such as the six-rowed plots used in this study, are too wasteful of land resources for general use. A logical solution might be an extension of Kern and Atkin's (40) formula for predicting the net change in yield due to a given unit of difference in adjacent row competition, at least for initial screening of lines.

Number of leaves per plant varied from 5 leaves per plant in Dochna to 24 leaves in Conspicuum in the world collection in India (55). Minimum variation of leaf number was found in Nervosum, Bicolor-Kafir, Dochna-Leoti, Dochna-Honey, Caffrorum-Bicolor, and Durra-Membranaceum. Groups having maximum mean number of leaves per plant were Conspicuum (16.3), Guineense (17.0), Membranaceum (16.4), Nigricans (17.1), and Caudatum-Kaura (16.2).

Leaf area, as a function of length and width, is an important attribute contributing to photosynthetic capability of the plant. Equally

important for the plant may be disposition of the leaves on the stalk. Several types with nearly opposite and erect leaves were found in Caudatums from Sudan by Murty (55). Several groups were found to have a mean leaf length of 65 to 81 centimeters and a mean leaf width up to 8.8 centimeters. A maximum leaf width of 11.0 cm was observed in some Nandyal and Durra types. Some lines with a mean leaf length of over 100 cm were found in Dochna, Roxburghii, Conspicuum, Caudatum, Caudatum-Kaura, and Caudatum-Durra. Several groups were homogeneous for those characters

Leaf angle variation among varieties of sorghum is common according to Quinby and Schertz (67). Some varieties have leaves that make an acute angle with the stem. However, the effects of this angle and its genetic control have not been studied in sorghum.

The number of leaves, leaf area, and leaf angle all contribute to form the visible photosynthesis capability of a plant. As long as new leaves are formed and contribute to the interception of more light, growth occurs in an exponential fashion accoring to Wit (87). But crops are often planted so densely that after some time a closed canopy is attained, in which new leaves do not contribute to the interception of more light but instead increase the mutual shading. From then on the crop grows at more or less a linear rate.

These dense canopies display their leaves in every direction. The way in which light is distributed over the individual leaves was first seriously considered by Boysen Jensen as quoted by Wit (87). He determined the relationship between the photosynthesis of a single leaf of mustard and light intensity and found the saturation curve. This was compared to the photosynthesis of a canopy with a leaf-area index of 3.5 in their natural position. The respiration of the canopy was about three

times higher than that of the horizontal leaf. At low light intensities the slope of both curves was the same. However the photosynthesis of the single leaf was at its maximum in light intensities which were too low for maximum photosynthesis of the crop canopy. Therefore the performance of the crop considerably surpasses that of the single leaves in the higher light ranges.

Wit (87) states that it has been found through computer models that the influence of variations in the canopy structure often is disappointingly small. He estimates that the gross photosynthesis of a closed crop surface is about 50,000 kg per ha (22 tons/A) for the growing season in the Netherlands and is reasonable for many crops. The potential production of above ground parts will then be about 25,000 kg per ha per year, which amounts to an average growth rate of about 200 kg per ha per day. This conclusion was corroborated by a comparison of the growth rate of various crops under near optimum conditions in the Netherlands. Oats, barley, Indian corn, peas, potatoes, sugar beets, grass, and gae all grow at a rate of about 200 kg per ha per day (175 lbs/A). Differences in dry matter yield are mainly due to differences in duration of growing season. The influence of weather was also surprisingly small, at least in grass production.

Loomis and Williams (44) feel that leaf arrangement is important to increase crop yields. Existing patterns of leaf arrangement are not necessarily best for intensive agriculture since natural selection, even under strong influence of man, has occurred principally in poverty environments and has emphasized many features of fitness in addition to productivity. Since the primary productivity in communities of autotrophic green plants is initially dependent upon photosynthesis, improvements in

the photosynthesis mechanisms should result in more efficient crops. Of particular interest is the influence of canopy architecture on photosynthesis through its effect on light distribution.

The most obvious feature of foliage canopies is density. Physiologists have long estimated percent cover and tried to relate this to production. Less than full cover not only permits solar radiation to escape interception by the photosynthetic apparatus (44) but also increases evaporation from the soil surface, a critical factor in areas of insufficient rainfall. Lack of density is of course a special problem in early stages of growth of annual row crops. Williams, Loomis and Lepley (85) worked with corn under the intense solar radiation of the southern California region and found a maximum rate of dry matter accumulation in their high plant plot of 460 lbs per day per A (52 gm/m^2 day) which occurred during a 12-day pretasseling period. Population densities ranged from 2,700 to 283,000 plants per A. Through this period, dry matter accumulation was directly correlated with the proportion of solar radiation intercepted by the canopy. They concluded that the energy-capturing capability of a corn crop is not fully utilized by present methods of culture for green forage. In another paper (86) these same authors reported lack of evidence in their experiment with corn for an optimum leaf-area index, that point at which crop growth rate reaches a peak and then declines at still higher leaf-area indices.

In a comparison of corn and soybean, Buttery (11) obtained slight indication of an optimum LAI. Within the LAI ranges utilized (approximately 1 to 5) the canopy arrangement of the soybean seemed no less efficient than that of corn. The mean net assimilation rate (NAR) of the corn plant was nearly twice that of the soybean, however, which may explain

the difference in productivity of the two species. Mean relative growth rate (RGR) and NAR increased for both species with increasing LAI, whereas mean crop growth rate and leaf area ratio decreased.

Williams et.al. (86) attempted to measure parameters of canopy architecture. A single-cross hybrid corn was grown under conditions of non-limiting nutrient and moisture conditions in central California. Seven population levels from 17,500 to 125,000 plants/ha (7,090 to 50,500 plants/A) resulted in LAI ranging from 3.5 to 8.5. They found that the amount of light intercepted by the foliage was a major detriment of crop growth during the vegetative stage. Erect leaves at tasseling permitted the deepest penetration of light. The yield of grain correlated well with crop growth rates up to an optimum population density, then decreased with increasing plant density. Maximum grain production was achieved at 48,700 plants/ha (19,700 plants/A), a figure close to that reported to give maximum grain in Indiana by Fery and Janick (21).

Shaw and Weber (71) simulated varying degrees of lodging in soybeans to produce changes in light interception and yield. Maximum light penetration occurred with a moderate amount of plant spread which simulated a small but definite amount of lodging. Greater light penetration, resulting in more of the canopy having light intensities above 150 foot-candles, generally resulted in greater yields. Higher oil content was generally associated with greater light penetration. Bean yield was positively correlated with both the amount of leaf area and the volume of canopy above the compensation point.

According to Monteith (53) most of the literature made available during the last 15 years which pertains to canopy architecture is concerned with computer models. He points out that this shows it is easier to

investigate light distribution at the desk rather than in the field. The measurement of leaf areas and angles is difficult and tedious.

With most agricultural crops, a basic pattern is imposed upon the community by grouping plants in regular patterns such as rows and by controlling density through seeding rates. This obviously influences the canopy morphology particularly in affecting the time to achieve full cover and in introducing a hedgerow characteristic to the surface of the canopy (44). Baker and Meyer (5) found that north-south rows produced higher yields of cotton than did east-west rows, and skip-rows (paired planted and paired unplanted) outyielded the solid stands. Increases in yield were related to the amount of light intercepted. Loomis and Williams (44) concluded from a number of reports that north-south rows gave a better pattern of light interception and higher yields than did east-west rows in cotton, soybeans, and apple trees. Optimum row spacing will be influenced by the potential size and character of the individual plants and by latitude.

The influence of variation in vertical density of leaves is relatively unexplored (44). Some work indicated a relationship of skylight occluded by a leaf of given width and various distances from a receiver point. Leaf size in relation to vertical separation strongly influences the angle of occlusion, hence the skylight pattern within a canopy. Large but widely separated leaves like those of sunflower may create a diffuse light pattern similar to a shorter community with small leaves like alfalfa. Most plants seem to have evolved with mechanisms for maintaining a certain ratio between leaf spacing and leaf width, but this fact has been overlooked in breeding for dwarf varieties of cultivated species. The short-internode types of grain sorghum have their wide leaves close together in relation to leaf width. Better canopy structure would result if leaf

width was reduced or if the leaves were more whorled.

Leaf width and length of sorghum parents and hybrids were measured by Quinby (63). He found the hybrids to have smaller leaves at maturity than their female parents. However, before maturity was reached, the leaves of hybrids were always larger than those of parental lines at comparable growth stages. Even embryonic leaves of hybrids were wider than those of parent lines, which Quinby attributed to early manifestation of hybrid vigor. The largest leaf blades of the hybrid plant were either the fourth or fifth from the top whereas the largest for the parents was the third from the top. Kirby and Atkins (42) also found hybrids to possess longer and wider leaves.

Average foliage angle alone may provide an inadequate description of canopy morphology for some communities (44). The distribution and totals of these angles should also be known. Several authors have foliar descriptions which serve to characterize some major differences in canopy morphology. Cucumber and clover were found to be highly planophile (horizontal leaves predominant), whereas timothy and corn had erectophile canopies. Corn leaf distribution corresponded to the surface elements of a sphere.

When light from near the zenith is abundant, and with nearly erect leaves in the upper strata of the canopy providing abundant gaps, horizontal leaves in the lower strata may be useful (44). This vertical-to-horizontal structure has been suggested frequently, but tests with models have failed to confirm the view according to Loomis et.al. (45).

Corn was found to have a wide range in canopy morphology. Russian and Estonian communities were strongly erectophile, the Netherland community weakly plagiophile (median angles dominant) and corn at Davis, California

was strongly planophile. Genotypes and environments were all different and the literature does not reveal time of maturity or stand densities used. Yet it is evident that the range of distributions for this one species is great (44).

Plant communities may show marked changes in canopy structure during growth. In a stand of perennial ryegrass, the proportion of horizontal leaves increased during growth as reported by Wit (87). Changes for corn are not as great. Loomis et.al. (46) noted that the upper leaves of corn shifted to a more horizontal habit after tasseling, but other authors have conflicting data from their investigations. Nevertheless, structural changes between juvenile and mature canopies are obvious for many species. Dicotyledonous species frequently show an early dominance of horizontal leaves, an advantage for maximizing light interception by the small leaf area of a young plant (44).

Flag leaf sheath length and flag leaf width were found by Hsu and Walton (31) to influence yield of spring wheat. These authors report other work which found flag leaf area to be associated with kernel number per ear and mean kernel weight, and found their own observations to agree although some environmental effects were present.

Tillering may contribute to boosting yields in hybrids. Most of the collection are grain types and therefore tend to have a limited number of tillers according to Murty (55). Nodal tillering, defined as more than 3 tillers per plant, was found in Conspicuum, Guineense, Bicolor-Kafir, Dochna-Amber, Caffrorum, Sumac, Nigricans-Feterita, Caudatum-Durra, and Durra-Dochna. Some groups involving Roxburghii, Dochna, and Nigricans did not tiller at all. Caudatum-Durra had potentially high tillering and several other desirable features including yield and grain quality.

Stem diameter, measured at the fourth internode after removing the leaf sheath by Murty (55), ranged from 0.6 to 2.7 centimeters as group means in individual cultures. Stem diameter is associated with peduncle size. Murty suggests selection for a juicy, thick stem. Largest stem diameters were found in the Nigerian and Ethiopian collections followed by Nervosum, Conspicuum, Nigricans, and Dobbs.

Lodging tendency is not necessarily associated with plant height. Murty (55) suggests that flexibility of the stem may be more important than resistance to lodging. Groups having a low mean tendency to lodge were Conspicuum, Dochna, Caffrorum-Roxburghii, Subglabrascens-Milo, Kaura combinations with Caudatum and Durra and several other Caudatum combinations. The Nigerian material did not show lodging in spite of heavy heads and tallness.

Head and Seed Characters

Length of panicle is a major component of yield, and is a useful measure for differentiating between species. Murty (55) also contends that head length is a major contributor to diversity in sorghum and is an important distinguishing character in each group in the classification. Variability of means for head length was high within groups, ranging from 15 to 45 centimeters. Nigricans and its hybrids had shorter panicles while Nerosum-Broomcorn and Conspicuum had longer panicles. Conspicuum, Dochna, Caudatum and its combinations had head length of about 30 cm. Groups with panicles shorter than 20 cm were Bicolor and its combinations, some of the Caffrorum combinations, Nigricans and its combinations, Dobbs, Caudatum and Durra. Murty suggests that the high variances for head length in Conspicuum, Nervosum-Kaoliang, Nervosum-Broomcorn, Nigricans,

Caudatum, and Sudanense may be due to introgressive hybridization in addition to the normal variation. In groups where heads were longer, the main rachis was slender, roundish, and tapering from the base to the tip, making them drooping. This was particularily true in Conspicuums, Dochna, and Sudanense. In Roxburghii the rachis was tough and undulating longitudinally. Generally, longer panicles were associated with lax or semilax heads with long primary branches.

Weight of 100 kernels is dependent on seed size and seed density. Group means ranged from 1.4 gms to 4.1 gms. Those groups with a mean of more than 3.0 gms were Conspicuum (3.5), Membranaceum (3.7), Caudatum (3.3), Caudatum-Kaura (4.1), Caudatum-Guineense (3.4), Caudatum-Durra (3.1), Durra (3.3), Cernum (3.7), and Subglabrescens-Milo (3.7). When examined with data on grain hardness and seed size, Caudatums and Conspicuums appeared to have both large grain size and higher grain density. Hardness rather than size appeared to contribute to grain weight in Durra and its combinations.

Weight of grain per panicles was considered to measure productivity of the plant. Murty (55) considered only the main panicle of tillering types. Group means ranged from 134 gms to 652 gms. Groups in which five panicles weighed over 400 gms were Caffrorum (434), Caffrorum-Birdproof (407), Caffrorum-Feterita (434), Caffrorum-Bicolor (652), Sumac (610), Nigricans-Guineense (444), Dobbs (400), Nigricans-Durra (452), Caudatum-Nigricans (449) and Nandyal (581). Most of these have long panicles. The intra-group variation for weight of grain was high. The Durra group did not have a high mean although the panicles are heavy, which lead Murty to suggest that components other than grain appear to be responsible for the panicle weight in Durra, as well as for the low grain production. The

Cernuums and Subglabrescens are similar to the Durra in this respect.

Many investigators have considered the factors of heads per plant, head length, seed weight, and weight per head. In 1956, Grafius (22) proposed a geometrical interpretation of yield. He felt that yield (W) could be represented as a sum due to effects of X = (number of panicles per unit area), Y = (average number of kernels per panicle) and Z = (mean kernel weight). This concept has been utilized in general in attempts to improve the components of yield of many crops.

Blum (8) considered the Y factor of Grafius to be of three parts in sorghum: number of whorls per panicle, number of branches per panicle, and number of grains per branch. These three components, together with the weight, or density, of the kernels determine the panicle weight factor. He compared nine grain sorghum hybrids to their parental lines for these factors in Israel. Parents differed significantly in the weight of grain per panicle and in each of the panicle weight components. Since parents did not differ in the number of grains per panicle, compensation apparently existed between the components which comprise this trait, and inter-parent variations in weight of grain per panicle were due mainly to variations in weight per grain. Six hybrids showed significant heterosis, defined by Blum as superiority over the better parent, in weight of grain per panicle. The three hybrids which did not exhibit this heterosis had a parent line superior for weight per grain. Only one hybrid showed heterosis for weight per grain; it's parents were both low for this trait. Most hybrids showed significant heterosis for number of grains per panicle and they differed significantly in number of whorls per panicle and the number of branches per whorl. Only number of grains per branch showed consistent and significant heterosis and this was found to occur mostly in the basal whorls,

least in the apical whorls. Blum concluded that heterosis did not result from an interaction between components but was due to consistent heterosi in a single over-dominant panicle weight component. Only RS 610 showed heterosis for component interaction (number of whorls per panicle and number of branches per whorl). A negative association exists between weight per grain and number of grains.

Kirby and Atkins (42) in Iowa measured expressions of heterosis for 13 characters of sorghum. Significant average heterosis was found for grain yield as well as a number of other characters, but number of seeds per head and number of heads per plant were not significant effects although the hybrids tended to exceed parental means for these effects. As did Blum, these authors found that seeds per head was the character most highly associated with grain yield. Biel and Atkins (7) also found a significant correlation between number of seeds per head and grain yield, and suggest that sorghum breeders base number of seeds per head in segregating populations as an important factor in their improvement programs.

Many other investigators have reported that number of seeds per head is the primary component influencing grain yield (7, 56, 60, 78). A negative relationship between seed size and seed number exists according to Quinby and Schertz (67). Large seed is generally thought to be desirable for feeding and milling, but no really definitive tests have been possible since all present hybrids have about the same size of seed. In breeding programs, progress towards large seed can be made if seed number is ignored, but if seed number is also considered, little progress is possible.

Quinby (63) found that hybrid panicles were heavier than parental panicles even though they were usually produced in less time. In this

study, the two most vigorous hybrids were those with seeds as small as those of the male parent. He felt that these hybrids had so many seeds that seed size per se was actually reduced.

Head length seems to have been of less concern, for fewer references allude to it. Chiang and Smith (14) found head length to be depressed by inbreeding. Head type was compared by Eastin and Sullivan (20). These men found that the open type of inflorescence continued to show an uptake of CO_2 through the soft dough stage of growth during illumination. In comparison, the closed type of inflorescence evolved CO_2 beginning at the milk stage under the same light conditions. While they were unable to translate the difference into yield data, the implications are important. Sorghum possesses an inflorescence ideally located to intercept maximum light if it is able to function in photosynthesis, as well as a vast array of modifications to the basic inflorescence design, such as long glumes.

Donald (19) proposed an ideotype for wheat with at least a moderate degree of tillering. Tillering is required to produce a large number of heads per plant with grass species.

Ishizuka (32) indicates that the new varieties of rice and their improved yields are associated with decreased plant height and increased numbers of effective tillers. For any variety, decisions on the density of plant population which will produce higher yields must be related to leaf arrangement and leaf area index (LAI). It is assumed that an optimum LAI will produce maximum yield. Since the number of leaves on a rice stem is rather fixed as is the plant population, LAI is governed to a great extent by the amount of tillering. However, Holt (30) working with hybrid sudangrass populations, did not find an increase of LAI by increasing plant numbers within a fixed row spacing. Chiang and Smith (15) found

tillering in sorghum to be largely controlled by additive gene action.

Under conditions of limited soil moisture and dense plant population, Blum (9) found most sorghum plants to produce a single panicle. As population decreased, plants of later maturing hybrids produced more tillers than did the earlier maturing hybrids.

Protein content analysis by Murty (55) in a few representatives of the 70 groups revealed considerable variation and a range of 8 to 18% protein. Groups with high protein content were Roxburghii (14.7%), Margaritiferum (14.5%), Nervosum-Broomcorn (17.8%), Dochna (15.9%), Caffrorum-Birdproof (16.7%), Caffrorum-Feterita (14.2%), Caffrorum-Durra (17.6%), and Durra-Dochna (14.2%).

Collins and Pickett (17) found little evidence for heterosis in protein content of the grain, although Malm (47) reported striking heterosis for protein content. However Malm reported significant specific combining effects, whereas only general combining effects were reported by Collins and Pickett. Liang (43) reported that the F_1 protein content was lower than that of the superior parent.

Lysine content was found to be negatively correlated with percent protein by Collins and Pickett (17), but weakly enough as to suggest breeding to combine high protein and high lysine. Lysine content was not significantly related to yield in their study.

MATERIALS AND METHODS

All data analyzed in this study trace to sorghum material grown at two locations in Indiana during the growing season of 1969. The Lafayette site, hereafter referred to as Lafayette, was at the Purdue University Agronomy Research Farm, located approximately six miles northwest of West Lafayette. The deep, fertile soil at this site is generally identified as a Chalmers silty clay loam. A contrasting environment was provided at the Purdue University Sand Field Experiment Station, hereafter termed the Sand Field, located eight miles southwest of Culver. The deep, extremely sandy soil of this site is drouth prone.

Selection of Parent Materials

All male lines used in this study were from the world collection. Initial evaluation and selection of males was made at Lafayette in the fall of 1967. At this time, large numbers of F_1 lines, synthesized as a part of the continuing sorghum program at Purdue University, were growing and available for inspection. Male parents were selected which induced diversity of type in their F_1 progeny. Diversity of F_1's for flag leaf size, leaf number and angle, head types and size, and plant height were selected factors. Subsequent checking showed that the male lines selected by these criteria in this material belonged to group number 38, Caudatum-Kafir. This was a reflection of the material available in previous years of the breeding program as well as to the generally superior pollen-producing capabilities of this subgroup.

To increase the representation of other subgroups, [illegible] previous years of the breeding program were examined in order to permit the inclusion of additional subgroups into this study. At least two lines were selected from each subgroup whenever possible. Little data were available on this material other than the existence of seed stocks, date bloom, and plant height. Selection thus was based on the availability of seed stocks and a range of plant heights in the male parent.

All selected male lines had limited amounts of seed available. These selected lines were planted on the Federal Experiment Station near Isabell, Puerto Rico in November of 1967. Seed stocks were increased there during the winter season. It was possible to cross many of these onto male-sterile (female) lines. This permitted an early evaluation of F_1 progeny at Lafayette in 1968. All Puerto Rican material was harvested in March and returned to Lafayette in time for the 1968 spring planting.

Two replications of the F_1 hybrids produced in Puerto Rico were grown at Lafayette in 1968. Those F_1's which were obviously lodging susceptible were discarded, as were those in which the male parent was of the B-genotype, thus incapable of pollen production in the F_1. Only slight lodging occurred in all of the Lafayette nurseries in 1968.

Hybrid Seed Production

All male and female lines were planted in the spring of 1968 at Lafayette in order to facilitate the synthesis of F_1's. At this time a total of 126 lines, representing a wide range of groups and morphological types, were planted. Split plantings of all female material were used to insure synchronization of blooming periods. Five male-sterile grain

identified as: Redlan, certified 56H372, bearing Kansas certified number 4RL4699; Combine Kafir-60, certified 55H276, Kansas certified number 4RL4687; Martin, certified 56H812, number ORP11881; Wheatland lot number 1350A (399); and KS-24, obtained from Kansas State University but not identified as to lot number.

Male-sterile heads were bagged prior to blooming or trimmed back well below opened florets if missed initially. Male heads were bagged at least 12 hours prior to pollen collection for crossing onto the male steriles. Each male line was crossed onto a minimum of five heads of each of the five male steriles whenever possible. In addition, five to ten heads of the male lines were selfed for pure seed stocks.

All seed supplies were threshed with care to maintain purity, cleaned and weighed. Not all crosses were equally successful. Available seed stocks of some hybrids were very limited. The Wheatland male sterile in particular proved to yield less seed than other male steriles and as a consequence this group was dropped from further testing. In addition, a number of male parents were so poor in pollen production that hybrids could not be made with them.

Field Technique

All tested lines were grown in 1969. A split plot design was utilized, with main plots being progeny of a single female line. The most complete complement of hybrids existed within the Redlan group of crosses. A total of 64 F_1 hybrids were planted within each of the Redlan groupings. Since each of the other three female groupings had less than a full complement available, RS-610 was used to bring the total number of entries to 64 within each block.

Table 1A of the appendix lists the male parents involved in the 1969 planting of the material by Indian Sorghum (IS) number, group, and classification.

One main plot also consisted of the male parents and the B-counterpart of the female lines. Within main plots, hybrids were assigned at random to subplots. Since different heights would be intermixed, six-rowed subplots were utilized so that interplot competition would be minimal or nonexistent in the center rows of each subplot. Johnson (36) has established the need of this type of plot in his paper which compared silage yields of four height groups when bordered by guard rows of different heights. All subplots at Lafayette were 15 feet long (4.6 m) and utilized 30-inch (76 cm) row spacing. Plots at the Sand Field were 15 feet long and utilized 20-inch (51 cm) row spacing. Two replications of all material were grown at each location. The Lafayette material was planted on May 19 and 20. Three days were required to plant the Sand Field location, May 15, 16, and 17.

Plant stands were generally good at Lafayette. They were thinned by hand to a stand of approximately 90,000 plants per acre (222,390 plants per ha).

A paucity of precipitation and the presence of drying conditions decimated plant stands at the Sand Field. No thinning was required nor possible. Seedling vigor was reduced by a lack of available phosphorus. Phosphorus was banded on in early July at a rate of 80 pounds per acre (90 kg/ha). In mid-June ammonium nitrate at 100 pounds per acre (112 kg/ha) was banded on. An application of 100-80-40 had been applied previous to plowing; it apparently was too deep in the soil profile to be available to the sorghum seedlings. Poor stands made yield estimations impossible

at this location.

Weeds were controlled at all locations by machine and hand cultivation. Control was excellent at Lafayette but poor at the Sand Field. At the latter location sorghum stands were too poor to compete with weeds.

Date Determination

1. Early vigor: rated at about six to eight inches of height. An index of 1 to 5 was used to estimate relative vigor, as indicated by relative plant development and vigor, with 1 indicating poor development.
2. Days to bloom: days from planting to time at which 50% of the panicles in the center rows of each subplot showed anthers.
3. Plant height: mean height of the plants in the center of each subplot.
4. Number of leaves: mean number of total leaves as counted from three randomly chosen plants.
5. Flag-leaf area: mean area of three randomly chosen flag leaves. Length × width, measured to the nearest centimeter, multiplied by the factor of 0.6 as determined by Beckman*.
6. Leaf area of third leaf: mean area of 3 randomly chosen leaves, the second leaf after the flag leaf. Area determined in the same method as measured for flag leaf.
7. Leaf canopy: rating of density of leaf cover. Mean of three ratings as judged by three observers rating independently. A scale of 1 through 5 was used, with 1 equaling poor utilization of the total

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

light available, 5 equaling a dense canopy. A 1 rating was awarded if the leaves did not meet in mid-row, a 5 if very little light penetrated to the soil surface between the rows.

8. Leaf angle: rating of overall angle of leaf canopy. Rated by three independent observers using an index of 1 to 3, with 1 being an upright leaf of approximately 30° in relation to the culm, a 2 rating indicating a general leaf angle of approximately 45° with the culm, and 3 forming a 90° angle or more with the culm.
9. Tillering: lines were rated on the apparent contribution of tillers to the overall yield. A mean of three independent observations was obtained, using a scale of 1 through 9, with 1 indicating 10% or less, 9 indicating 80 to 90%.
10. Relative stalk diameter of the population: a mean of three independent observations rating stalk diameter as 1, slender, to 3, heavy, robust.
11. Length of head: mean length in centimeters of five randomly chosen heads. Measured from the attachment of the lowest panicle branches to the tip florets.
12. Grain yield per head: each head measured for length was threshed individually. Grams of threshed grain per head was recorded.
13. Weight of 100 seeds: mean of duplicate samples electronically counted from the bulked head samples. Weighed in grams.
14. Protein content: nitrogen content of the subplot sample × 6.25.
15. Lysine content: grams of lysine per 100 grams of protein.
16. Grain yield per acre: determined by multiplying number of heads harvested by mean weight of threshed grain from five random heads. This product was then multiplied by 1.8 to convert to pounds/A.

17. Milligrams of protein per seed: determined by multiplying individual seed weight by percent protein.

18. Milligrams of lysine per seed: protein content per seed multiplied by percent lysine.

19. Lodging: estimated percent of plants lodged at harvest.

The numbers of lines for which good data were available was reduced throughout the growing season. Some lines showed early-season lodging, especially at Lafayette, and these were eliminated from further consideration at that time (Appendix Table 2A). As pointed out previously, stands were poor and erratic at the Sand Field. However, the greatest problem occurred in September of 1969 at Lafayette when several inches of rain were followed by high winds. As a consequence, severe lodging occurred in all taller lines both in this material and in the rest of the Purdue sorghum nursery. Twisting of culms was so extensive in much of the taller material that is was impossible to trace a head back to its origin. All of these factors combined to reduce the amount of data available for both sites. The number of lines for which information existed at both sites was reduced so as to minimize the need to calculate missing plot information, resulting in 19 male lines being considered. These unfortunately do not adequately reflect the many groups which could have been included under more fortunate circumstances. Data, averaged by entry over replication, are shown in Appendix Table 3A.

Mathematical Models

The analysis of variance for the combining ability data has the following model:

$$Y_{ijk} = \mu + R_i + \gamma(i) + F_j + RF_{ij} + \delta(ij) + M_k + MR_{ij} + FM_{jk} + MFR_{ijk} + \varepsilon(ijk)l$$

where:

Y_{ijk} = the observation on an entry between the ith replication and the jth female and the kth male.

μ = the general mean

R_i = the effect of the ith replication, i = 1,2.

$\gamma(i)$ = the restriction of replication.

F_j = the effect of the jth female, j = 1 to 4.

RF_{ij} = the interaction effect of the ith replication and the jth female.

$\delta(ij)$ = the restriction placed in randomization by the split-plot design.

M_k = the effect of the kth male, k = 1 to 19.

MR_{ik} = the interaction of the ith replication and the kth male.

FM_{jk} = the interaction of the jth female and the k male.

MFR_{ijk} = the interaction of the ith replication, jth female, and the kth male.

$\varepsilon(ijk)l$ = error effect associated with each subplot.

The form of analysis for combining effects for the 76 hybrids was as follows:

Source	df	Expected mean squares
Replications	1	$\sigma_\varepsilon^2 + 19\sigma_\gamma^2 + 76\sigma_\delta^2 + 76\phi_R$
Restriction on reps	0	$\sigma_\varepsilon^2 + 19\sigma_\gamma^2 + 76\sigma_\delta^2$
Females	3	$\sigma_\varepsilon^2 + 19\sigma_\gamma^2 + 38\phi_F$
Error (a) = r × f	3	$\sigma_\varepsilon^2 + 19\sigma_\gamma^2 + 19\phi_{RF}$
Restriction of blocks	0	$\sigma_\varepsilon^2 + 19\sigma_\gamma$
Males	18	$\sigma_\varepsilon^2 + 8\phi_M$
Female × male	54	$\sigma_\varepsilon^2 + 2\phi_{MF}$
Male × reps	18	$\sigma_\varepsilon^2 + 4\phi_{MR}$
Error (b) = m × f × r	54	$\sigma_\varepsilon^2 + \phi_{MFR}$

In the above analysis all interactions involving replications were assumed to be zero. This permitted using error (b) to test female x male and male effects. The male x reps interaction was pooled with error (b). Replications x females was also assumed to be zero, which permitted this mean square to be considered an estimate of error (a) with which to test female mean squares. There is no valid error term with which to test replication mean squares.

A one-way analysis of variance was conducted on the data in order to estimate phenotypic and genetic correlation coefficients for all measured characters. Within and between (cross-products) variances werecalculated and applied in the following formulas to determine correlation coefficients.

$$\text{Phenotypic correlation } (r_p) = \frac{M_{x1x2}}{\sqrt{(M_{x1}) \cdot (M_{x2})}}$$

where M_{x1x2} = the phenotypic mean cross product between pairs of characters, obtained from the analysis of variance. M_{x1} and M_{x2} = phenotypic mean squares of $_{x1}$ and $_{x2}$.

$$\text{Genotypic correlation } (r_g) = \frac{Cov_{g_{x1x2}}}{\sqrt{\sigma^2 g_{x1} \cdot \sigma^2 g_{x2}}}$$

where $Cov_{g_{x1x2}}$ = (Genotype mean cross products - error mean cross products)/reps.

where $\sigma^2 g_{x1} \cdot \sigma^2 g_{x2}$ was estimated from analysis of variance effects by: (Genotype MS - error MS)/reps, and is further considered to represent total (additive and non-additive) genetic effects.

To examine further for the presence of SCA, a method proposed by Oldemeyer and Rush (57) was utilized. Means of individual crosses were adjusted by adding or subtracting from them the deviations of the means of all respective crosses of each parent from the test average. Using the computation for percent protein as shown in Appendix Table 3A, an example is as follows:

CK-60 × 7 produced grain of 11.1% protein

Test average = 11.2%

All CK-60 hybrids averaged 10.8%

All male 7 hybrids averaged 11.8%

Adjusted mean for CK-60 × 7 is:

$$X_a = 11.1 - (10.8 - 11.2) - (11.8 - 11.2) = 10.9\%$$

This adjustment removes the general combining effect of both parents. If SCA effect did occur, adjusted means of individual crosses should deviate significantly from the test mean. The range of non-significance was determined by multiplying the standard deviation by the appropriate level of "t".

RESULTS AND DISCUSSION

Combining Ability

An analysis of combining ability was determined for the 19 hybrids of the 19 male lines and 4 female lines used in this study. Analysis of variance is presented in Table 2 for the 19 characters studied.

Female and male effects are considered to estimate general combining effects (GCA) whereas the female × male interaction is considered an estimation of specific combining ability (SCA) (7, 39). GCA is equated with genes which possess additive effects so that gene action or effect is linear. The presence of additive effects is assumed to indicate that the plant breeder could incorporate the desired character into an inbred or self-fertilizing population. SCA is a reflection of dominance and/or epistatic gene action which is non-linear. This type of effect is best exploited through hybrid production or perhaps early synthetics in those species not adaptable to the ready production of hybrids.

In this study male effects (GCA) were highly significant for all 19 characters studied. Sprague and Tatum (74) suggested in corn that GCA would be more important in relatively untested lines, but as testing progressed and only the superior lines remained, SCA effects would become more important. Kambal and Webster (39) found greater GCA than SCA effects in their report, even though the 19 male lines represented a more advanced population than used in this study. They attributed much of the reduced female effect to the relatively narrow genetic base represented

Table 2. Combining ability analysis of variance for 19 characters of 76 F_1 hybrids grown at Lafayette in 1969.

Source	df	Mean Squares					
		Early Vigor	Days to 50% Bloom	Leaf Number	Flag Leaf Area	Third Leaf Area	Tillering
Replications	1	1.112	17.79	.164	2644	3972	.870
Females	3	.779	109.34*	.428	25207	12210	1.454
Error (a)	3	1.385	10.12	1.971	6121	1135	1.754
Males	18	5.364**	467.28**	32.870**	83269**	26277**	8.204**
Females × Males	54	.672*	16.26**	2.372**	7424**	4930**	1.072
Reps × Males	18	(.570)	(7.71)	(.664)	(5858)	(2162)	(.737)
Error (b)	54	.319	6.30	.916	2611	1927	.789
Total	151						
C. V. (a)		33.2	3.9	9.8	37.8	9.5	34.8
C. V. (b)		17.4	3.1	6.4	24.7	12.6	23.1

Source	df	Mean Squares				
		Stem Size	Canopy	Leaf Angle	Lodging	Plant Height
Replications	1	.870	.658	.341	.800	388
Females	3	.119	1.067	.548	6.456	3925**
Error (a)	3	.129	.283	.218	5.042	22
Males	18	.506**	4.061**	.498**	99.310**	36243**
Females × Males	54	.065	.240*	.166**	7.473**	2791**
Reps × Males	18	(.038)	(.152)	(.054)	(1.046)	(197)
Error (b)	54	.085	.135	.053	1.403	221
Total	151					
C. V. (a)		15.6	15.0	19.3	42.9	1.9
C. V. (b)		11.8	10.5	9.5	21.9	6.0

Table 2. Continued.

Source	df	Mean Squares			
		Percent protein	Percent lysine	Head length	Threshed grain/head
Replications	1	2.658	.0206	1.48	345
Females	3	7.223	.3425	32.41*	320
Error (a)	3	1.485	.0801	2.39	870
Males	18	4.610**	.1427**	79.17**	1126**
Females × Males	54	1.072	.0540**	3.83**	227*
Reps × Males	18	(.664	(.0207	(1.67	(129
Error (b)	54	.620)	.0264)	2.14)	138)
Total	151				
C. V. (a)		10.9	13.1	6.1	49.1
C. V. (b)		7.1	7.3	5.6	19.4

Source	df	Mean Squares			
		100 grain weight	Grain yield	Protein per seed	Lysine per seed
Replications	1	.552	10,886,182	1.638	.00054
Females	3	.109	3,515,087	.543*	.00072*
Error (a)	3	.089	16,552,847	.036	.00003
Males	18	1.595**	14,617,468**	3.434**	.00137**
Females × Males	54	.144	3,410,126	.365**	.00011
Reps × Males	18	(.049)	(2.285,379)	(.183)	(.00006)
Error (b)	54	.039	2,318,482	.135	.00005
Total	151				
C. V. (a)		10.4	53.7	5.9	7.8
C. V. (b)		7.2	19.7	11.8	14.4

in existing male sterile lines. In the F_1 population studied by Niehaus and Pickett (56) GCA effects were generally more important than were SCA effects, although both components were highly significant for the eight characters studied. Their study involved three exotic lines and five adapted selections.

In this study female effects were highly significant for plant heigl As shown in Table 3, hybrids having KS-24 as the female parent averaged about 20 cm less in height than hybrids with the other three female parents.

Significant female effects were indicated for date of bloom, head length, mg of protein per seed, and mg of lysine per seed. Summary data in Table 3 indicate that KS-24 and Martin hybrids averaged 81 days to flowering, whereas Redlan and CK-60 hybrids bloomed in an average of 84 and 83 days, respectively. Head lengths of hybrids of the four females ranged from 24.1 to 26.3 cm, and were found to be significantly different in the analysis. The quality factors of protein and lysine per seed were also indicated to possess significant female differences. Protein per seed ranged from 3.14 mg per seed for Redlan hybrids to 3.41 mg for Marti hybrids. The Martin hybrids therefore had an average of 8.6% more protei per seed than did the Redlan hybrids. Redlan hybrids also were lowest in lysine content per seed. The mean of 0.0638 mg/seed for Redlan hybrids was nearly 13% less than the average of the highest group, the KS-24 hybrids at 0.0733 mg/seed. Martin hybrids had the highest percentage of protein as well as protein per seed. KS-24 hybrids had the second highest protein content but the highest percent lysine, grain yield, and mg lysine per seed, even though its hybrids possessed the smallest seeds.

Table 3. Mean performance of F_1 hybrids by male and female parents.

Male No. or Female	Early Vigor	Days to Bloom	Number of Leaves	Flag Leaf Area	Third Leaf Area	Tillering
7	2.0	71	11	239	349	3.3
11	4.3	77	14	137	292	2.0
13	3.8	76	13	169	298	2.8
20	2.6	75	14	158	328	5.0
22	2.4	80	16	118	289	5.7
24	4.1	91	16	187	364	4.3
29	2.6	73	13	189	384	4.9
30	4.6	79	11	305	435	3.0
33	2.8	87	16	143	311	2.6
34	4.0	94	16	209	337	2.8
36	4.3	86	13	472	465	5.2
38	4.1	92	18	135	325	4.6
40	4.5	80	13	440	474	4.4
41	3.5	80	16	130	307	3.6
42	4.0	88	17	124	295	2.7
43	4.4	91	15	278	370	4.0
45	3.5	73	13	173	398	4.0
49	2.5	77	12	199	375	4.1
50	3.5	93	17	123	314	3.6
KS-24	3.6	81	14	240	378	3.8
Martin	3.7	81	14	214	352	3.6
Redlan	3.5	84	15	188	349	3.9
CK-60	3.4	83	14	184	335	4.0

Table 3. Continued.

Male No. or Female	Stalk Size	Canopy	Leaf Angle	Lodging	Plant Height	% Protein	% Lysine
7	2.0	1.7	2.8	0	135	11.8	2.08
11	2.0	2.7	2.7	7	329	12.7	2.31
13	1.9	3.3	2.5	7	300	120	2.19
20	2.2	3.3	2.6	1	175	108	2.23
22	2.2	3.7	2.6	0	183	10.4	2.26
24	2.6	3.8	2.5	8	308	11.2	2.06
29	2.2	3.0	2.8	0	161	10.1	2.49
30	1.8	3.1	2.5	7	321	12.3	1.99
33	2.5	4.4	2.0	2	193	11.1	2.29
34	2.5	3.9	1.9	7	317	11.8	2.19
36	2.5	3.9	2.5	9	308	10.7	2.07
38	2.4	4.5	2.3	4	199	10.2	2.19
40	2.4	4.3	2.4	9	236	11.4	1.98
41	2.6	2.8	2.5	9	307	12.0	2.02
42	2.5	3.7	2.2	9	303	11.2	2.02
43	2.1	3.3	2.3	6	229	10.6	2.09
45	2.6	4.5	2.5	6	210	10.4	2.11
49	2.2	3.5	2.4	0	143	10.9	2.34
50	2.4	4.1	2.0	9	270	12.0	2.14
KS-24	2.3	3.6	2.4	5	228	11.3	2.29
Martin	3.3	3.6	2.6	6	249	11.8	2.14
Redlan	2.3	3.7	2.3	5	249	11.0	2.06
CK-60	2.3	3.3	2.4	5	248	10.8	2.15

Table 3. Continued.

Male No. or Female	Head Length	Grain per Head	Number of Grains/hd.	100 Kernel Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
7	26.0	37	1600	2.31	5840	2.72	.0565
11	23.5	65	1850	3.45	7160	4.37	.0998
13	23.8	53	1680	3.16	6330	3.80	.0826
20	29.9	54	1670	3.23	6340	3.52	.0785
22	28.4	48	1580	3.03	6300	3.17	.0708
24	26.1	82	2770	2.97	8110	3.31	.0673
29	26.9	43	1850	2.33	6690	2.36	.0586
30	25.4	59	1600	3.69	6820	4.53	.0902
33	27.9	52	2120	2.46	7980	2.74	.0616
34	30.8	73	2480	2.94	10080	3.50	.0754
36	23.8	73	2820	2.60	8950	2.76	.0576
38	24.5	55	2440	2.25	7530	2.28	.0502
40	29.5	62	1960	3.16	6820	3.61	.0705
41	19.9	68	2090	3.27	7570	3.93	.0791
42	22.9	74	2470	2.99	10550	3.36	.0674
43	23.0	67	2040	3.28	8270	3.46	.0727
45	24.8	59	2500	2.36	8660	2.45	.0518
49	27.4	46	2020	2.28	6970	2.48	.0578
50	19.3	65	2460	2.66	7840	3.17	.0677
KS-24	26.3	61	2170	2.80	8110	3.22	.0733
Martin	25.8	56	1950	2.87	7650	3.41	.0721
Redlan	24.1	63	2230	2.83	7770	2.14	.0639
CK-60	25.5	58	1970	2.94	7380	3.18	.0678

Hybrids of Redlan and CK-60 ranked below hybrids of KS-24 and Martin for these quality factors.

Highly significant SCA effects were noted for date of bloom, number of leaves, flag- and third-leaf areas, leaf angle, late lodging, plant height, percent lysine, head length, and protein per seed. The allelic series known to exist for maturity (date of bloom) and plant height explains the occurrence of these two interactions. Significant levels of female × male interactions were also indicated for early vigor, canopy cover, and threshed grain per head.

An examination of the coefficients of variation (C. V.) for the 19 variables measured or rated indicated that most C. V. values were within acceptable limits. Flag-leaf area would appear to be much more variable than third-leaf area and the high C. V. associated with tillering would indicate that a refinement of measurement or method of sampling should be considered. Lodging was associated with definite field effects (environmental) and is known to be highly variable. The high C. V. associated with grain yield may be due in part to the variation found also in threshed grain per head since the latter factor was used to calculate yield. An increase in harvested plot size with careful attention to actual area harvested should improve C. V. for yield.

Analyses for SCA effects were determined for five yield and quality factors following the procedure proposed by Oldemeyer and Rush (57). These analyses are shown in Tables 4 through 9. Both positive and negative effects were noted and the results essentially agreed with the analyses of combining effects presented in Table 2. Two instances of positive SCA were calculated for lysine percent, two for seed weight, two for grain yield, four for mg of protein per seed, and one for mg of lysine per seed.

Table 4. Original and adjusted protein contents of F_1 hybrids grown at Lafayette.

	Female Parent								
	CK-60		Redlan		Martin		KS-24		
Male	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	Means
7	11.1	10.9	11.4	11.0	12.4	11.2	12.1	11.3	11.8
11	10.5	9.4*	13.2	11.9	13.8	11.7	13.1	11.5	12.7
13	11.9	11.5	12.5	11.9	11.9	10.5	11.7	10.8	12.0
20	11.6	12.4	9.9	10.5	10.7	10.5	11.1	11.4	10.8
22	9.7	10.9	10.2	11.2	11.5	11.3	10.1	10.8	10.4
24	10.4	10.8	11.6	11.8	12.2	11.6	10.4	10.3	11.2
29	9.4	10.9	9.8	11.1	10.2	10.7	11.0	12.0	10.1
30	11.2	10.5	11.9	11.0	12.5	10.8	13.5	12.3	12.3
33	10.2	10.7	11.2	11.5	11.5	11.0	11.4	11.4	11.1
34	11.1	10.9	10.6	10.2	13.8	11.6	11.7	11.0	11.8
36	10.1	11.3	10.5	11.5	10.1	10.3	11.0	11.7	10.4
38	10.4	11.3	10.0	10.7	10.9	10.8	11.4	11.8	10.7
40	9.2	10.6	10.0	11.2	10.6	11.0	10.8	11.7	10.2
41	10.3	10.5	11.3	11.3	13.0	12.2	10.8	10.5	11.4
42	12.7	12.3	11.9	11.3	11.8	10.4	11.6	10.7	12.0
43	11.4	11.8	9.8	10.0	13.1	12.5	10.5	10.4	11.2
45	10.2	11.2	10.5	11.3	11.0	11.0	10.6	11.1	10.6
49	11.4	12.1	10.7	11.2	11.0	10.7	10.5	10.7	10.9
50	12.0	11.6	12.0	11.4	11.9	10.5	12.1	11.2	12.0
Means	10.8		11.0		11.8		11.3		11.2

s = 0.6
range (t = .05) = 12.4 to 10.0
* indicates adjusted mean varies significantly from mean.

Table 5. Original and adjusted lysine contents of F_1 hybrids grown at Lafayette.

	Female Parent								
	CK-60		Redlan		Martin		KS-24		
Male	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	Means
7	2.02	2.10	2.16	2.34	2.00	2.10	2.15	2.11	2.08
11	2.53	2.38	2.04	1.99	2.28	2.15	2.37	2.10	2.31
13	2.08	2.05	1.95	2.02	2.02	2.01	2.72	2.57*	2.19
20	1.89	1.82	2.33	2.36	2.42	2.37	2.29	2.10	2.23
22	2.22	2.12	2.33	2.33	2.03	1.95	2.48	2.26	2.26
24	2.15	2.25	1.92	2.12	1.87	1.99	2.29	2.27	2.06
29	2.47	2.14	2.37	2.14	2.69	2.38	2.42	1.97	2.49
30	2.02	2.15	1.77	1.95	2.02	2.12	2.15	2.11	1.99
33	2.50	2.37	1.94	1.91	2.28	2.17	2.42	2.17	2.29
34	2.11	2.08	2.37	2.44	1.99	1.98	2.29	2.14	2.19
36	2.00	2.05	2.00	2.15	2.16	2.23	2.28	2.21	2.11
38	2.17	2.26	2.01	2.20	2.02	2.13	2.10	2.07	2.07
40	2.29	2.26	2.18	2.25	2.16	2.15	2.14	1.99	2.19
41	2.06	2.23	1.76	2.04	1.82	2.02	2.28	2.34	1.98
42	1.89	2.03	1.93	2.17	2.17	2.33	2.09	2.11	2.02
43	1.99	2.13	2.08	2.32	1.90	2.06	2.12	2.14	2.02
45	2.06	2.13	2.00	2.17	2.01	2.10	2.31	2.26	2.09
47	2.24	2.06	2.15	2.07	2.60	2.44*	2.38	2.08	2.34
50	2.25	2.23	1.87	1.95	2.27	2.27	2.17	2.03	2.14
Means	2.15		2.06		2.14		2.29		2.16

s = 0.14
range (t = .05) = 2.43 to 1.78
* indicates adjusted mean varies significantly from mean.

Table 6. Original and adjusted seed weight of F_1 hybrids grown at Lafayette.

	Female Parent								
	CK-60		Redlan		Martin		KS-24		
Male	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	Means
7	2.28	2.75	2.32	2.90	2.38	2.92	2.27	2.88	2.31
11	3.39	2.72	3.55	2.99	3.46	2.86	3.41	2.88	3.45
13	3.18	2.80	3.32	3.05	3.04	2.73	3.09	2.85	3.16
20	3.12	2.67	3.04	2.70	3.16	2.78	3.61	3.30*	3.23
22	3.15	2.90	2.93	2.79	3.49	3.31	2.56	2.43*	3.03
24	3.10	2.91	3.24	3.16	2.76	2.64	2.76	2.71	2.97
29	2.46	2.91	2.07	2.63	2.40	2.92	2.40	2.99	2.33
30	3.80	2.88	3.75	2.95	3.52	2.68	3.70	2.93	3.69
33	2.72	2.59	2.83	3.26*	2.30	2.69	2.43	2.89	2.46
34	3.28	3.12	2.04	1.99*	3.22	3.13	3.21	3.19	2.94
36	2.44	2.86	2.20	2.73	2.18	2.67	2.60	3.16	2.36
38	2.60	2.82	2.65	2.94	2.48	2.73	2.65	2.97	2.60
40	2.34	2.87	2.33	2.97	2.27	2.87	2.07	2.74	2.25
41	3.13	2.75	3.37	3.10	3.28	2.97	2.87	2.63	3.16
42	3.62	3.13	3.12	2.74	3.29	2.87	3.04	2.69	3.27
43	3.05	2.84	2.92	2.82	3.33	3.19	2.65	2.58	2.99
45	3.39	2.89	3.22	2.83	3.12	2.69	3.38	3.02	3.28
49	2.45	2.95	2.35	2.96	2.10	2.67	2.21	2.85	2.28
50	2.81	2.93	2.54	2.77	2.70	2.89	2.57	2.83	2.66
Means	2.94		2.83		2.87		2.80		2.86

s = 0.20
range (t = .05) = 3.25 to 2.47
* indicates adjusted mean varies significantly from mean.

Table 7. Original and adjusted grain yields of F_1 hybrids grown at Lafayette.

	CK-60		Redlan		Martin		KS-24		
Male	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	Means
7	5095	7327	6283	8125	6302	8268	5687	7186	5842
11	6940	7851	5956	6477	8398	9043	7358	7536	7163
13	7071	8814	5382	6735	6022	7499	6849	7859	6331
20	6631	8368	6816	8163	5445	6916	6456	7460	6337
22	6566	8341	5375	6750	7341	8850	5913	6955	6299
24	8035	7995	9371	8941	7641	7335	7410	6637	8114
29	7266	8649	5939	6932	6584	7701	6977	7627	6691
30	7745	9001	7850	8716	5725	6715	5954	6477	6818
33	6595	6685	9952	9642	7938	7762	7450	6807	7984
34	12053	10045*	6195	3797*	8327	6053	13755	11014*	10082
36	8621	8040	7662	7791	7770	6923	9469	8155	8655
38	6809	5937	10386	9124	8124	6986	10466	8861	8946
40	6716	7260	6167	6321	8260	8538	8975	8786	7530
41	4990	6243	8327	9190	6970	7957	6997	7517	6821
42	8125	6631	10438	8554	10794	9034	9914	6687	9568
43	8485	6011	9765	6901	12231	9491	11712	8505	10548
45	7000	7705	9128	8543	7257	6796	8792	7864	8269
49	6683	7785	7678	8390	6945	7791	6582	6951	6972
50	7891	8123	7859	7701	7198	7164	8422	7921	7842
Means	7380		7770		7646		8113		7727

s = 1108
range (t = .05) = 9899 to 5555.
* indicates adjusted mean varies significantly from mean.

Table 8. Original and adjusted protein per seed content of F_1 hybrids grown at Lafayette.

	Female Parent								
	CK-60		Redlan		Martin		KS-24		
Male	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	Means
7	2.55	3.26	2.63	3.11	2.95	3.16	2.76	3.16	2.72
11	3.55	2.61*	4.68	3.51	4.79	3.35	4.46	3.21	4.37
13	3.79	3.42	4.16	3.53	3.60	2.73	3.64	2.96	3.80
20	3.66	3.22	3.03	2.71	3.37	2.78	4.02	3.62	3.52
22	3.07	3.33	2.99	3.02	4.02	3.78*	2.58	2.53	3.17
24	3.22	3.34	3.75	3.64	3.40	3.02	2.89	2.70	3.31
29	2.33	3.40	2.03	2.87	2.45	3.02	2.64	3.40	2.36
30	4.27	3.17	4.46	3.13	4.39	2.79	5.00	3.59	4.53
33	2.28	2.97	3.19	3.65	2.65	2.84	2.84	3.22	2.74
34	3.62	3.55	2.15	1.85	4.45	3.88*	3.78	3.40	3.50
36	2.46	3.44	2.32	3.07	2.20	2.68	2.82	3.49	2.45
38	2.68	3.35	2.65	3.09	2.70	2.87	3.01	3.46	2.76
40	2.15	3.30	2.34	3.26	2.40	3.05	2.23	3.07	2.28
41	3.22	3.04	3.85	3.44	4.27	3.59	3.10	2.61*	3.61
42	4.55	4.05*	3.71	2.98	3.90	2.90	3.54	2.73	3.93
43	3.45	3.62	2.86	2.70	4.35	3.92*	2.77	2.53*	3.36
45	3.45	3.42	3.93	3.13	3.42	2.89	3.59	3.25	3.46
49	2.77	3.72	2.50	3.22	2.30	2.75	2.34	2.98	2.48
50	3.37	3.63	3.01	3.04	3.20	2.96	3.11	3.06	3.17
Means	3.18		3.14		3.41		3.22		3.17

s = 0.28
range (t = .05) = 3.72 to 2.62
* indicates adjusted mean varies significantly from mean.

Table 9. Original and adjusted lysine per seed content of F_1 hybrids grown at Lafayette.

	Female Parent								
	CK-60		Redlan		Martin		KS-24		
Male	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	$\bar{X}$	$\bar{X}_2$	Means
7	.0510	.0653	.0566	.0748	.0591	.0637	.0593	.0681	.0565
11	.0899	.0609	.0955	.0704	.1091	.0758	.1047	.0702	.0998
13	.0788	.0670	.0811	.0732	.0725	.0564*	.0986	.0813	.0826
20	.0680	.0603	.0706	.0668	.0830	.0710	.0922	.0790	.0785
22	.0681	.0681	.0699	.0738	.0813	.0770	.0640	.0585	.0708
24	.0692	.0727	.0717	.0791	.0626	.0618	.0658	.0638	.0673
29	.0576	.0698	.0480	.0641	.0655	.0734	.0633	.0700	.0586
30	.0860	.0666	.0791	.0636	.0887	.0650	.1068	.0819*	.0902
33	.0566	.0658	.0632	.0763	.0605	.0654	.0659	.0696	.0616
34	.0762	.0716	.0512	.0505*	.0886	.0797	.0855	.0754	.0754
36	.0492	.0682	.0460	.0689	.0475	.0622	.0643	.0778	.0518
38	.0582	.0714	.0533	.0704	.0544	.0633	.0644	.0721	.0576
40	.0494	.0700	.0515	.0760	.0517	.0680	.0480	.0631	.0602
41	.0660	.0663	.0679	.0721	.0771	.0731	.0710	.0658	.0705
42	.0853	.0770	.0716	.0672	.0856	.0730	.0740	.0602	.0791
43	.0690	.0724	.0594	.0667	.0823	.0814	.0589	.0568	.0674
45	.0713	.0694	.0678	.0698	.0687	.0625	.0829	.0755	.0727
49	.0621	.0751	.0537	.0706	.0597	.0684	.0555	.0630	.0578
50	.0756	.0787	.0558	.0628	.0722	.0710	.0673	.0649	.0677
Means	.0678		.0639		.0721		.0733		.0693

s = 0.0064
range (t = .05) = 0.0818 to 0.0568.
* indicates adjusted mean varies significantly from mean.

Comparison of Parents and F_1's for Quality Factors

Each array of hybrids was compared to its male and female parent for yield and grain quality parameters. This permitted the determination of percent heterosis, calculation of simple correlation of parental means with F_1 means, or comparison of various F_1 factors. These data are presented in Tables 10 through 15.

For the measurement of percent protein as shown in Table 10, hybrids averaged 1% less protein than male parents, although they were 4% better than their female parents. Performance for percent lysine (Table 11) was similar in scale to that determined for percent protein, but was slightly superior to either male or female parent.

Weight of 100 grains of the hybrids averaged 17% more than their parental means; only only F_1 failed to exceed its midparent mean as shown in Table 12. It is this feature which appeared to explain generally the increase of protein and lysine per seed for the contribution from the male lines. An exception were hybrids of KS-24, whose progeny were highest in lysine per seed and second best for protein per seed despite having the lowest 100-grain weights of the four female lines. F_1 mean seed weight exceeded that of the male parent for 16 of 19 groups, and the female means for all four comparisons.

As shown on Table 13, hybrids averaged about 24% more grain per acre than their inbred parents. Male 43 appeared to greatly enhance total yield capability of its hybrids, followed by males 34 and 42. Hybrids of KS-24 averaged about 4% more in yield than Redlan crosses about 6% more than Martin crosses, and 9% more than hybrids of CK-60.

Table 10. Comparison of parental and F_1 hybrid protein content (percent).

Inbred Identification	Percentage Protein			
Male	Male Parent	F_1 mean 1/	Midparent 2/	% Heterosis 3/
7	11.9	11.8	11.5	2.6
11	10.6	12.7	10.8	17.6
13	11.3	12.0	11.2	7.1
20	10.8	10.8	10.9	- 1.0
22	10.1	10.4	10.6	- 1.9
24	10.8	11.2	10.9	2.7
29	10.7	10.1	10.9	- 7.3
30	12.9	12.3	11.9	3.4
33	13.4	11.1	12.2	- 9.0
34	14.0	11.8	12.5	- 5.6
36	13.0	10.4	12.0	-13.3
38	10.4	10.7	10.7	0
40	11.4	10.2	11.2	- 8.9
41	12.5	11.4	11.8	- 3.4
42	12.4	12.0	11.7	2.6
43	10.2	11.2	10.6	5.7
45	11.3	10.6	11.2	- 5.7
49	12.0	10.9	11.5	- 5.2
50	12.8	12.0	11.9	.8
Means	11.7	11.2		- 1.0
Female	Female Parent			
CK-60 (B)	10.4	10.8	11.1	- 2.7
Redlan (B)	10.6	11.0	11.2	- 1.8
Martin (B)	12.7	11.8	12.2	- 3.3
KS-24 (B)	10.3	11.3	11.0	2.7
Means	11.0	11.2		1.2

1/ Mean of all hybrids which possessed that particular parent.
2/ (Male mean + grand female mean)/2 or reverse.
3/ (Midparent - F_1)/midparent.

r, male mean to F_1 mean = 0.317.
r, female mean to F_1 mean = 0.854.

Table 11. Comparison of parental and F_1 hybrid lysine content (percent of protein).

Inbred Identification	Percent Lysine			
Male	Male Parent	F_1 mean[1]	Midparent[2]	% Heterosis[3]
7	2.10	2.08	2.14	-2.8
11	2.23	2.31	2.20	5.0
13	2.12	2.19	2.14	2.3
20	2.26	2.23	2.22	0
22	2.45	2.26	2.31	-2.2
24	2.27	2.06	2.22	-7.2
29	2.35	2.49	2.26	10.2
30	1.71	1.99	1.94	2.5
33	2.04	2.29	2.10	9.0
34	1.76	2.19	1.96	11.7
36	1.86	2.14	2.02	4.5
38	2.19	2.07	2.18	-5.0
40	2.27	2.19	2.22	-1.4
41	1.71	1.98	1.94	2.1
42	2.20	2.02	2.18	-7.3
43	2.14	2.02	2.16	-6.5
45	2.24	2.09	2.21	-5.4
49	2.18	2.34	2.18	7.3
50	2.04	2.14	2.10	1.9
Means	2.11	2.16		1.0
Female	Female Parent			
CK-60 (B)	2.41	2.15	2.29	-5.7
Redlan (B)	2.05	2.06	2.08	-1.0
Martin (B)	1.87	2.14	1.99	7.5
KS-24 (B)	2.31	2.29	2.21	3.2
Means	2.17	2.16		1.0

1/ Mean of all hybrids which possessed that particular parent.
2/ (Male mean + grand female mean)/2 or reverse.
3/ (Midparent - F_1)/midparent.

r, male mean to F_1 mean = 0.473* (confidence interval (0.05) = .05 to .75)
r, female mean to F_1 mean = 0.435

Table 12. Comparison of parental and F_1 hybrid grain size.

Inbred Identification	100-Grain Wt. (g)			
Male	Male Parent	F_1 mean 1/	Midparent 2/	% Heterosis 3/
7	2.01	2.31	2.18	5.9
11	2.30	3.45	2.32	48.7
13	2.14	3.16	2.24	41.1
20	2.86	3.23	2.60	24.2
22	2.73	3.03	2.54	19.3
24	2.92	2.97	2.64	12.5
29	1.77	2.33	2.06	13.1
30	3.86	3.69	3.10	19.0
33	2.65	2.46	2.50	- 1.6
34	3.19	2.94	2.77	6.1
36	2.11	2.36	2.23	5.8
38	2.32	2.60	2.34	11.1
40	1.95	2.25	2.15	4.7
41	2.80	3.16	2.57	23.0
42	2.64	3.27	2.50	30.8
43	2.36	2.99	2.36	26.7
45	3.23	3.28	2.79	17.6
49	1.97	2.28	2.16	5.6
50	2.35	2.66	2.35	13.2
Means	2.53	2.86		17.2
Female	Female Parent			
CK-60 (B)	2.58	2.94	2.55	15.3
Redlan (B)	2.49	2.83	2.51	12.7
Martin (B)	2.43	2.87	2.48	15.7
KS-24 (B)	1.91	2.80	2.22	26.1
Means	2.35	2.86		17.5

1/ Mean of all hybrids which possessed that particular parent.
2/ (Male mean + grand female mean)/2 or reverse.
3/ (Midparent - F_1)/midparent.

r, male mean to F_1 mean = 0.733**, confidence interval (0.05) = .273 to .851.
r, female mean to F_1 mean = 0.756.

Table 13. Comparison of parental and F_1 hybrid grain yield.

Inbred Identification	Yield of Grain/Acre (lbs)			
Male	Male Parent	F_1 mean[1]	Midparent[2]	% Heterosis[3]
7	6208	5842	6490	-10.0
11	8168	7163	7473	- 4.2
13	5460	6331	6119	3.5
20	5686	6337	6232	1.7
22	6995	6299	6886	- 8.5
24	5936	8114	6357	27.6
29	4122	6691	5450	22.8
30	5803	6818	6290	8.4
33	4464	7984	5621	42.0
34	3745	10082	5262	91.6
36	6667	8655	6722	28.8
38	7099	8946	6938	28.9
40	7031	7530	6904	9.1
41	6645	6821	6711	1.6
42	6050	9568	6414	49.2
43	6016	10548	6397	64.9
45	6280	8269	6529	26.7
49	4937	6972	5857	19.0
50	2850	7842	4814	62.9
Means	5798	7727		24.5
Female	Female Parent			
CK-60 (B)	5865	7380	5831	26.6
Redlan (B)	7012	7770	6405	21.3
Martin (B)	6805	7646	6301	21.4
KS-24 (B)	7430	8113	6614	22.7
Means	6778	7727		23.0

1/ Mean of all parents which possessed that particular parent.
2/ (Male mean + grand female mean)/2 or reverse.
3/ (Midparent - F_1)/midparent.

r, male means to F_1 means = 0.112.
r, female means to F_1 means = 0.954*, confidence interval (0.05) = 0.999 to .104.

Table 14. Comparison of parental and F_1 hybrid protein per seed.

Inbred Identification	Milligrams of protein/seed			
Male	Male Parent	F_1 Means 1/	Midparent 2/	% Heterosis 3/
7	2.40	2.72	2.50	8.8
11	3.50	4.37	3.05	43.3
13	2.43	3.80	2.52	5.08
20	3.09	3.52	2.84	23.9
22	2.77	3.17	2.68	18.3
24	3.15	3.31	2.87	15.3
29	1.89	2.36	2.75	-14.2
30	5.00	4.53	3.80	19.2
33	3.55	2.74	3.08	-11.0
34	4.50	3.50	3.55	- 1.4
36	2.75	2.45	2.67	- 8.2
38	2.42	2.76	2.51	10.0
40	2.23	2.28	2.41	- 5.4
41	3.58	3.61	3.09	16.8
42	3.26	3.93	2.93	34.1
43	2.41	3.36	2.51	33.9
45	3.65	3.46	3.12	10.9
49	2.36	2.48	2.48	0
50	3.01	3.17	2.80	13.2
Means	3.05	3.23		19.5
Female				
CK-60 (B)	2.69	3.18	2.87	10.8
Redlan (B)	2.62	3.14	2.83	11.0
Martin (B)	3.12	3.41	3.08	10.7
KS-24 (B)	1.97	3.22	2.51	28.3
Means	2.60	3.24		15.2

1/ Mean of all hybrids which possessed that particular parent.
2/ (Male mean + grand female mean)/2 or reverse.
3/ (Midparent - F_1)/midparent.

r, male means to F_1 means = 0.689**, confidence interval (0.05) = .872 to .351.
r, female means to F_1 means = 0.550.

Table 15. Comparison of parental of F_1 hybrid lysine per seed.

Inbred Identification	Milligrams of lysine/seed			
Male	Male Parent	F_1 mean 1/	Midparent 2/	% Heterosis 3/
7	.0510	.0565	.0538	4.8
11	.0781	.0998	.06672	48.5
13	.0521	.0826	.0542	52.4
20	.0697	.0785	.0630	24.6
22	.0678	.0708	.0620	14.2
24	.0716	.0673	.0639	5.4
29	.0443	.0586	.0525	11.6
30	.0854	.0902	.0708	27.4
33	.0725	.0616	.0644	- 4.3
34	.0794	.0754	.0678	11.2
36	.0511	.0518	.0537	- 3.6
38	.0532	.0576	.0547	5.3
40	.0506	.0502	.0534	- 6.0
41	.0609	.0705	.0586	20.3
42	.0716	.0791	.0639	23.8
43	.0513	.0674	.0538	25.3
45	.0816	.0727	.0689	5.5
49	.0516	.0578	.0539	7.2
50	.0612	.0677	.0587	15.3
Means	.0632	.0693		15.2
Female	Female Parent			
CK-60 (B)	.0664	.0678	.0648	4.6
Redlan (B)	.0540	.0639	.0586	9.0
Martin (B)	.0587	.0721	.0610	18.2
KS-24 (B)	.0456	.0733	.0544	34.7
Means	.0662	.0693		16.1

1/ Mean of all hybrids which possed that particular parent.
2/ (Male mean + grand female mean)/2 or reverse.
3/ (Midparent - F_1)/midparent

r, male means to F_1 means = 0.688** (Confidence interval (0.06) = .350 to .872.
r, female means to F_1 means = -0.346.

Comparisons of mg of protein and lysine per seed (Table 14 and 15) show heterosis of 15.2% to 19.5% over midparent values. Six sets of the hybrids produced protein per seed equal to or less than midparent values. All other male combinations exceeded midparent values. Males 11, 13, 42, and 43 especially appeared to enhance mg of protein per seed. Hybrids with KS-24 exhibited the greatest percentage increase of protein per seed, although hybrids of Martin were superior in absolute amounts. Redlan crosses were lowest in protein per seed. Two male lines showed negative heterosis for mg of lysine per seed; all other lines had lysine contents higher than midparent values. Males 11, 13, 30, 41, and 43 were determined to confer high levels of heterosis for mg of lysine per seed. When hybrids were compared to their female parents, the superior level of KS-24 progeny is of special note. Parental level of KS-24 was the lowest in level of lysine, which explains the large (34.7%) reading of heterosis, but most important was the high total lysine per seed. KS-24 hybrids averaged 0.0012 mg or 1.6% more lysine per seed than Martin crosses, 7.5% more than CK-60 hybrids, and 12.8% more than Redlan progeny. As indicated in Table 11, KS-24 hybrids averaged highest in percent lysine also.

Simple correlation coefficients were calculated with the previous parameters, comparing parental means to F_1 means. Significant correlations would tend to indicate that within the population studied, performance of the parent could be used to indicate relative F_1 performance. Grafius (23) quoted other plant breeders who showed that high yielding parents tended to produce high yielding hybrids. Thorne and Fehr (80) also found soybean population means to be predictable from parental performance, but Harlan (27) indicated that the value of exotic germplasm may not be apparent until

it is studied as a parent. Collins and Pickett (17) indicated that their sorghum hybrids tended to reflect parental performance. In the present study, significant simple correlation values were determined for male lysine percentage to F_1 lysine percentage performance. Highly significant values were determined for the association of the weight of grain for the male lines to F_1 grain weight and for the two values of male protein per seed and lysine per seed to F_1 content. These values are shown at the bottom of Tables 10 through 15.

Scatter diagrams were constructed to illustrate comparisons considered to be of value to a sorghum quality improvement program. In Figure 1 the comparison of 100-grain weight to yield of grain per acre is shown to have little relationship in the F_1 population studied. Correlation coefficients determined for these comparisons (Tables 16 through 20) support the low simple correlation obtained for the data points of Figure 1.

High intercharacter correlations were determined for the association of plant height and 100-grain weight. Figure 2 illustrates the data points for mean F_1 data, showing that taller genotypes produced heavier grains. All intercharacter correlation comparisons of Tables 16 through 20 support the data illustrated.

Quinby and Schertz (67) and Blum (8) have reported that seed size and seed number per head are negatively correlated. Derived data from Table 3 was used to establish data points for Figure 3, showing that this population followed that same trend. Niehaus and Pickett (56) found little relationship between seed weight and number of seeds per head in the F_1 generation they studied, and that number of seeds per

Table 16. Intercharacter phenotypic and genotypic correlation coefficients for the 19 hybrids with male sterile CK-60 as female parent.

	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Head Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		.447*	.357	.040	-.169	-.226	.175	.078	.181	.807**	.790**	.050	-.031	-.391	.612**	.269	.440	.231	.285
2	.543		.885**	-.409	-.518*	.052	.764	.405	-.362	.620**	.516*	.095	-.028	-.056	.552*	-.088	.578**	-.017	-.044
3	.423	.926		-.654**	-.651**	.222	.754**	.428	-.331	.549*	.438	.014	.046	-.118	.390	-.035	.372	-.016	-.001
4	.053	-.483	-.708		.654*	.115	-.193	.068	.346	-.170	-.333	-.236	-.110	-.090	-.200	-.235	-.175	-.250	-.346
5	-.177	-.580	-.797	.768		.073	-.392	-.111	.257	-.303	-.315	-.218	-.079	.072	-.064	.054	-.033	.002	-.074
6	-.305	.027	.235	.122	.171		.527*	.579*	-.046	.070	-.382	-.460*	-.105	.041	-.081	-.324	-.172	-.439	-.555*
7	.262	1.04	1.11	-.269	-.587	.728		.583**	-.165	.427	.098	-.230	-.032	-.063	.287	-.305	.215	-.309	-.388
8	.135	.434	.487	.012	-.164	.583	.791		-.423	.134	-.188	-.445*	.255	.098	-.053	-.399	-.035	-.485*	-.441
9	.174	-.455	-.400	.443	.430	-.187	-.308	-.451		.036	-.076	.119	-.136	-.513	-.211	.089	-.374	.138	.088
10	.889	.633	.581	-.169	-.326	-.078	.588	.159	.017		.807**	.241	-.340	-.435	.613	.393	.455*	.404	.327
11	.879	.526	.404	-.434	-.377	-.427	.108	-.211	-.098	.831		.320	-.182	-.197	.790**	.640**	.677**	.617**	.656**
12	-.008	.133	-.003	-.249	-.325	-.577	-.611	-.598	.308	.289	.374		-.595**	-.301	.085	.403	.180	.718**	.559*
13	.003	-.044	.083	-.228	-.134	-.120	.057	.348	-.418	-.404	-.214	-.531		.133	-.140	-.388	-.140	-.517*	-.110
14	-.451	-.051	-.121	-.150	.060	.051	-.090	.091	-.634	.466	-.213	-.300	.098		.054	-.093	.069	-.205	-.183
15	.867	.674	.527	-.520	-.226	-.150	.446	-.144	-.312	.723	.910	.263	-.339	-.014		.480*	.807**	.396	.414
16	.344	-.098	-.042	-.293	.138	-.433	-.520	-.463	.077	.416	.672	.447	-.477	-.114	.554		.325	.923**	.890**
17	.782	.865	.671	-.627	-.158	-.240	.314	-.187	-.635	.626	.932	.554	-.464	-.043	.793	.439		.328	.315
18	.273	-.013	-.026	-.289	.022	-.562	-.635	-.585	.201	.443	.665	.708	-.529	-.215	.527	.946	.552		.902**
19	.368	-.053	-.005	-.443	-.050	-.705	-.680	-.519	.035	.355	.700	.639	-.186	-.213	.482	.893	.435	.930	

Phenotypic values above the diagonal, genotypic below.

* Significant at 5%, ** significant at 1% level.

Table 17. Intercharacter phenotypic and genotypic correlation coefficients for the 19 hybrids with male sterile KS-24 as female parent.

	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Head Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		.327	-.008	.530*	.387	-.202	-.004	.509*	-.171	.512*	.552*	.232	-.300	-.372	.484*	.211	.507*	.269	.180
2	.425		.723**	.130	.140	-.095	.635**	.633**	-.395	.709*	.572**	-.091	-.308	-.132	.778**	-.010	.692**	-.047	-.133
3	.003	.771		-.468*	-.451*	-.068	.554*	.390	-.449*	.594**	.451*	-.133	-.011	-.098	.552	.114	.365	.021	.018
4	.581	.168	-.476		.852**	.001	.102	.322	.102	-.057	-.003	-.129	-.312	-.040	.188	-.240	.431	-.223	-.298
5	.524	.128	-.499	.942		.232	.201	.217	.187	-.158	-.118	-.160	-.468*	.015	.152	-.291	.399	-.268	-.401
6	-.200	-.053	-.117	.064	.315		-.059	-.175	.440	-.345	-.365	-.416	-.043	.053	-.132	-.031	.063	-.194	-.188
7	-.004	.870	.699	.030	.247	-.130		.571	-.336	.232	.084	-.401	-.130	.065	.544*	-.307	.555*	-.402	-.426
8	.595	.693	.4124	.379	.296	-.258	.784		-.586**	.282	.141	-.280	-.058	-.018	.418	-.199	.422	-.247	-.260
9	-.282	-.518	-.607	.199	.230	.566	-.428	-.690		-.344	-.196	.152	.127	-.034	-.434	.027	-.266	.059	.116
10	.561	.765	.622	-.059	-.179	-.372	.359	.297	-.406		.901**	.273	-.268	-.455*	.755**	.379	.518*	.385	.312
11	.608	.608	.465	.005	-.108	-.470	.119	.138	-.231	.921		.429	-.129	-.303	.731**	.570*	.494*	.603**	.554*
12	.536	-.087	-.042	-.344	-.353	-.528	-.996	-.529	.560	.502	.791		-.158	-.245	.015	.471*	-.139	.743**	.659*
13	-.564	-.581	-.059	-.502	-.791	-.117	-.223	-.046	.091	-.456	-.216	.443		.361	-.338	.049	-.335	-.230	.281
14	-.488	-.121	-.119	-.080	-.004	.151	.013	.009	-.118	-.504	-.318	-.365	.473		-.155	-.054	-.058	-.118	-.037
15	.669	1.02	.699	.165	.148	.040	.765	.630	-.580	.931	.936	.124	-.561	-.325		.334	.854**	.250	.158
16	.255	.060	.151	-.266	-.324	-.013	-.325	-.206	.096	.414	.635	.778	.347	-.067	.363		.015	.938**	.918**
17	.621	.907	.465	.477	.488	.401	.851	.593	-.393	.578	.619	-.260	-.659	-.241	.855	-.028		-.048	-.133
18	.365	.016	.085	-.284	-.325	-.163	-.540	-.283	.068	.444	.704	.869	-.013	-.123	.315	.985	-.084		.954**
19	.227	-.111	.073	-.357	-.476	-.150	-.530	-.272	.235	.322	.607	.848	.501	-.031	.167	.962	-.219	.977	

Phenotypic values above the diagonal, genotypic below.

* Significant at 5%, ** significant at 1% level.

Table 18. Intercharacter phenotypic and genotypic correlation coefficients for the 19 hybrids with male sterile Redlan as female parent.

	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Head Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		.406	.050	.244	.131	-.226	.194	.083	-.177	.541*	.629**	.529*	-.586**	-.375	.331	.336	.200	.464*	.286
2	.540		.508*	.038	-.076	-.028	.776**	.386	-.492*	.521*	.504*	-.008	-.336	-.279	.476*	-.053	.649**	-.055	-.205
3	.104	.542		-.592**	-.748**	-.322	.481*	.328	.059	.158	.303	.037	-.001	-.001	.290	.146	.257	.109	.152
4	.327	.548	-.597		.875**	.443*	.076	.093	-.162	.036	-.124	-.301	.011	-.040	-.144	-.342	.035	-.352	-.427
5	.230	-.090	-.795	.940		.512*	-.043	-.013	-.234	.088	-.146	-.310	-.129	-.048	.007	-.246	.149	-.294	-.428
6	-.156	-.021	-.368	.464	.681		.054	.411	.046	-.224	-.439	-.676**	.263	.362	.090	-.430	.031	-.573**	-.580**
7	.282	1.03	.520	.149	-.057	.138		.291	-.196	.424	.264	-.125	-.147	-.194	.413	-.192	.688**	-.201	-.283
8	.206	.440	.369	.101	.002	.409	.408		-.404	.061	-.129	-.326	.055	.269	.114	-.260	.007	-.319	-.361
9	-.207	-.704	.111	-.196	-.412	-.039	-.351	-.474		-.198	-.045	-.086	.289	.118	-.088	.123	-.248	.074	.229
10	.643	.557	.117	.062	.134	-.220	.519	.099	-.248		.846**	.409	-.825**	-.527*	.735**	.491*	.673**	.508*	.278
11	.792	.524	.344	-.145	-.179	-.563	.368	-.162	-.040	.916		.490*	-.713**	-.555*	.651**	.562**	.531*	.667**	.514*
12	.776	-.021	.056	-.311	-.450	-.803	-.130	-.324	-.270	.519	.552		-.592**	-.412	.074	.563**	-.084	.797**	.706**
13	-.740	-.388	.042	-.067	-.163	.258	-.179	.034	.332	-.942	-.784	-.699		.359	-.651**	-.586**	-.552*	-.645**	-.343
14	-.539	-.302	.011	-.048	-.050	.440	-.234	.350	.126	-.565	-.596	-.548	.434		-.133	-.077	-.255	-.205	-.124
15	.317	.542	.443	-.194	-.032	.188	.883	.229	-.128	.944	.727	.019	-.794	-.269		.490*	.797**	.373	.187
16	.400	-.048	.108	-.358	-.286	-.493	-.249	-.313	.209	.523	.659	.619	-.652	-.083	.552		.168	.946**	.900**
17	.159	.787	.367	.046	.192	.139	1.295	.079	-.381	.958	.632	-.233	-.674	-.486	.790	.187		.070	-.138
18	.596	-.059	.132	-.364	-.369	-.654	-.263	-.350	.073	.568	.685	.811	-.715	-.239	.408	.961	.070		.936**
19	.401	-.223	.201	-.480	-.534	-.701	-.362	-.419	.251	.333	.545	.718	-.468	-.152	.206	.930	-.206	.949	

Phenotypic values above the diagonal, genotypic below.

* Significant at 5%, ** significant at 1% level.

Table 19. Intercharacter phenotypic and genotypic correlation coefficients for the 19 hybrids with male sterile Martin as female parent.

	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Head Length	Grain Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		.398	.199	.348	.447*	-.160	.179	.335	-.386	.777**	.677**	.113	-.480*	-.353	.554*	.360	.381	.317	.150
2	.467		.716**	-.139	-.048	-.313	.558	.424	-.589**	.639**	.654**	.337	-.334	-.427	.697**	.096	.615**	.5	.081
3	.244	.791		-.629**	-.490*	-.125	.531*	.333	-.301	.524*	.464*	.319	-.366	-.304	.783**	.360	.621**	.383	.255
4	.378	-.177	-.767		.835**	.209	-.047	.275	-.068	-.058	-.146	-.355	-.001	.183	-.429	-.431	-.210	-.424	-.467*
5	.550	-.069	-.658	1.133		.213	-.139	.343	-.012	.107	.050	-.289	.010	.128	-.136	-.425	-.212	-.386	-.447*
6	-.242	-.442	-.140	.287	.159		.038	.132	.499*	-.472*	-.494*	-.612**	.234	.440	-.343	-.251	-.322	-.420	-.383
7	.153	.818	.634	-.142	-.527	.084		.416	-.346	.158	-.017	-.092	.013	-.230	.450*	-.136	.701**	-.126	-.165
8	.370	.479	.376	.316	.404	.210	.570		-.413	.268	-.060	-.300	-.083	.153	.215	-.229	.178	-.265	-.360
9	-.486	-.629	-.311	-.069	.032	.663	-.524	-.443		-.539*	-.361	-.124	.260	.429	-.305	.046	-.452*	-.016	.085
10	.854	.654	.537	-.066	.124	-.567	.252	.292	-.554		.851**	.377	-.628**	-.505*	.711**	.421	.420	.460*	.235
11	.769	.681	.481	-.168	.020	-.602	-.024	.051	-.389	.871		.574**	-.552*	-.416	.725**	.590**	.380	.548**	.496*
12	.045	.412	.362	-.429	-.291	-.791	-.111	-.341	-.256	.419	.644		-.493*	-.001	.449*	.614**	.284	.838**	.712**
13	-.529	-.518	-.423	.018	-.029	.384	.184	-.021	.392	-.807	-.702	-.476		.066	-.422	-.436	-.241	-.497*	-.068
14	.279	-.421	-.348	.154	.124	.531	-.452	.127	.450	-.510	-.452	-.041	.231		-.417	-.044	-.447*	-.030	-.030
15	.685	.943	.951	-.047	-.225	-.505	.597	.195	-.325	.893	.867	.605	-.436	-.606		.429	.771**	.499*	.377
16	.380	.101	.381	-.500	-.467	-.251	.119	-.216	.022	.427	.629	.631	-.566	-.017	.576		.164	.943**	.874**
17	.456	.852	.744	-.240	-.421	-.592	.976	.125	-.587	.534	.442	.353	-.063	-.680	.738	.266		.242	.152
18	.311	.245	.411	-.497	-.413	-.487	-.127	-.269	-.086	.481	.711	.837	-.572	-.030	.666	.951	.355		.802**
19	.171	.062	.304	-.579	-.513	-.423	-.086	-.344	.048	.234	.543	.792	-.280	.032	.629	.890	.397	.946	

Phenotypic value above the diagonal, genotypic below.

* Significant at 5%, ** significant at 1% level.

Table 20. Intercharacter phenotypic and genotypic correlation coefficients for the 4 female lines (B counterpart) and 19 males.

	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Head Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		-.124	-.071	.419*	.112	.067	-.097	.374	-.096	.602*	.678*	.272	-.534*	-.116	.195	.342	.029	.404*	.201
2	-.094		.817*	-.359	.018	-.141	.641*	.469*	-.566*	-.139	-.150	.083	.117	.060	.197	-.078	-.280	-.053	.035
3	-.073	.846		-.597*	-.382	-.405*	.616*	.352	-.400	.059	.009	-.103	.215	.099	.483*	.078	-.025	-.003	.146
4	.485	-.373	-.626		.728**	.532**	-.186	.268	.182	.065	.126	.053	-.279	-.058	-.147	.022	.096	.048	-.090
5	.161	.050	-.387	.823		.354	.020	.257	.019	-.029	-.065	.099	-.186	.104	-.151	-.049	-.158	-.003	-.081
6	.188	-.218	-.543	.698	.674		.025	.187	.024	-.246	-.107	.067	-.087	-.294	-.435*	.002	-.281	.034	-.010
7	-.062	.685	.721	-.220	-.091	.051		.595**	-.359	-.065	-.185	.021	.056	-.037	.217	-.059	-.043	-.051	.003
8	.547	.469	.361	.339	.380	.214	.681		-.298	.031	-.010	-.010	-.095	-.153	.213	-.157	.229	-.146	-.187
9	-.161	-.637	-.472	.215	-.006	.170	-.439	-.362		-.1.07	-.093	-.634	.333	.152	-.031	-.292	.335	-.466*	-.437*
10	.683	-.48	.059	.057	-.030	-.320	-.068	.036	-.098		.849**	.289	-.451*	.153	.489*	.637**	-.013	.641**	.549**
11	.739	-.145	.014	.130	-.077	-.136	-.196	.000	-.103	.873		.179	-.399	-.035	.479*	.737**	.072	.684**	.618**
12	.225	.161	-.061	.006	.049	.117	.069	.150	-.798	.335	.198		-.768**	.235	-.349	.243	-.537**	.602**	.326
13	-.654	.057	.172	-.309	-.180	-.134	.115	-.280	.445	-.569	-.445	-.846		-.318	.103	-.331	.203	-.596**	-.184
14	-.169	.067	.090	-.045	.156	-.401	-.010	-.178	.161	.162	-.038	.276	-.400		-.026	.123	-.065	.222	.054
15	.234	.186	.498	-.127	-.127	-.620	.265	.199	-.039	.513	.508	-.390	.076	-.066		.457*	.579**	.210	.359
16	.350	-.067	.110	-.004	-.084	-.038	-.062	-.107	-.319	.664	.753	.193	-.335	.129	.507		.004	.917**	.941**
17	.006	-.333	-.029	.121	-.230	-.352	-.019	.253	.392	-.017	.089	-.715	.170	-.113	.568	.010		-.219	-.142
18	.402	-.024	.038	.012	-.052	.021	-.042	-.061	-.534	.686	.715	.557	-.627	.240	.250	.920	-.266		.892**
19	.168	.050	.175	-.138	-.114	-.050	.046	-.145	-.490	.578	.663	.260	-.255	.052	.405	.964	-.222	.909	

Phenotypic values above the diagonal, genotypic below.

*Significant at 5%, ** Significant at 1% level.

head had the largest direct effect on yield.

Percent protein was positively correlated with 100-grain weight, as illustrated in Figure 4. Both simple, phenotypic, and genotypic correlations were relatively high as shown in Figure 4 and Tables 16-19. Inbred or parent line data do not agree in magnitude with hybrid data, however, since lower correlation coefficients were determined from inbred data as shown in Table 20.

Grain weight was negatively correlated with parent lysine as illustrated in Figure 5 and the tables of intercharacter correlations. The notable exception is the performance of KS-24 hybrids. As listed in Table 17, the phenotypic correlation of these two components was slightly positive and the genotypic correlation was decidedly positive.

Total protein and total lysine, measured in milligrams per seed, were always highly correlated with seed weight in this study. This is illustrated in Figures 6 and 7, and values are presented in Tables 16 through 20. Heavier grain contained more protein and lysine.

Protein content of the seed remained relatively constant over yield, as shown in Figure 8, however, groups varied in mean performance. Hybrids of CK-60 (Table 16) and Martin (Table 19) were determined to be positively correlated. KS-24 hybrids (Table 17) and inbred parents (Table 20) were negatively correlated. As shown in Table 18, hybrids of Redlan were determined to be nearer to zero for the correlation coefficient.

Protein content of the seed and lysine content of the seed were positively associated with percent protein. These associations are shown in Figures 9 and 10, and in Tables 16 to 20. Correlation of mg lysine with percent protein was relatively less for parent lines than for hybrids.

FIG 1. Grain yield /A. as a function of 100-grain weight of 19 F_1 groups.

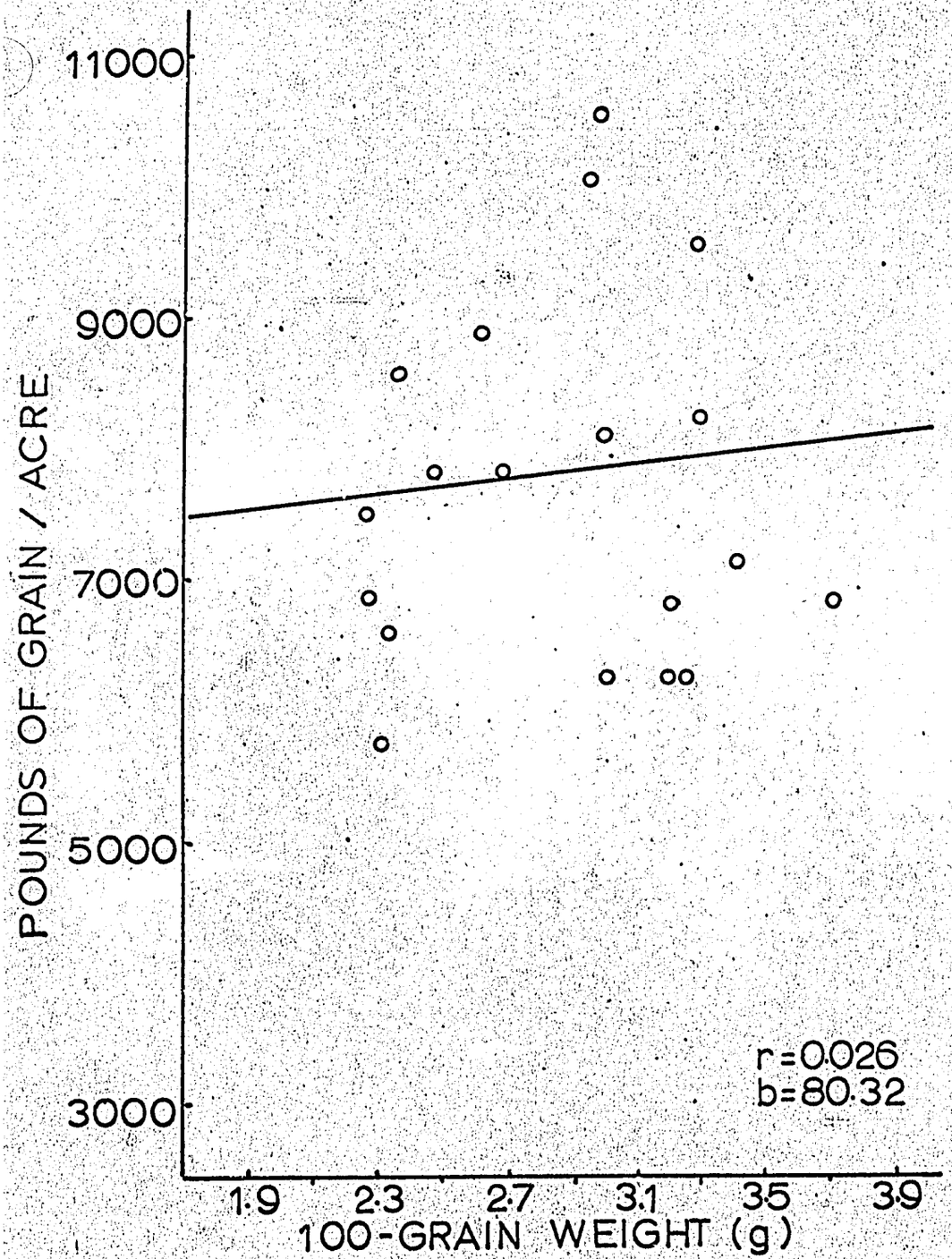


FIG 2. Plant height compared with 100-grain weight of 19 F_1 groups.

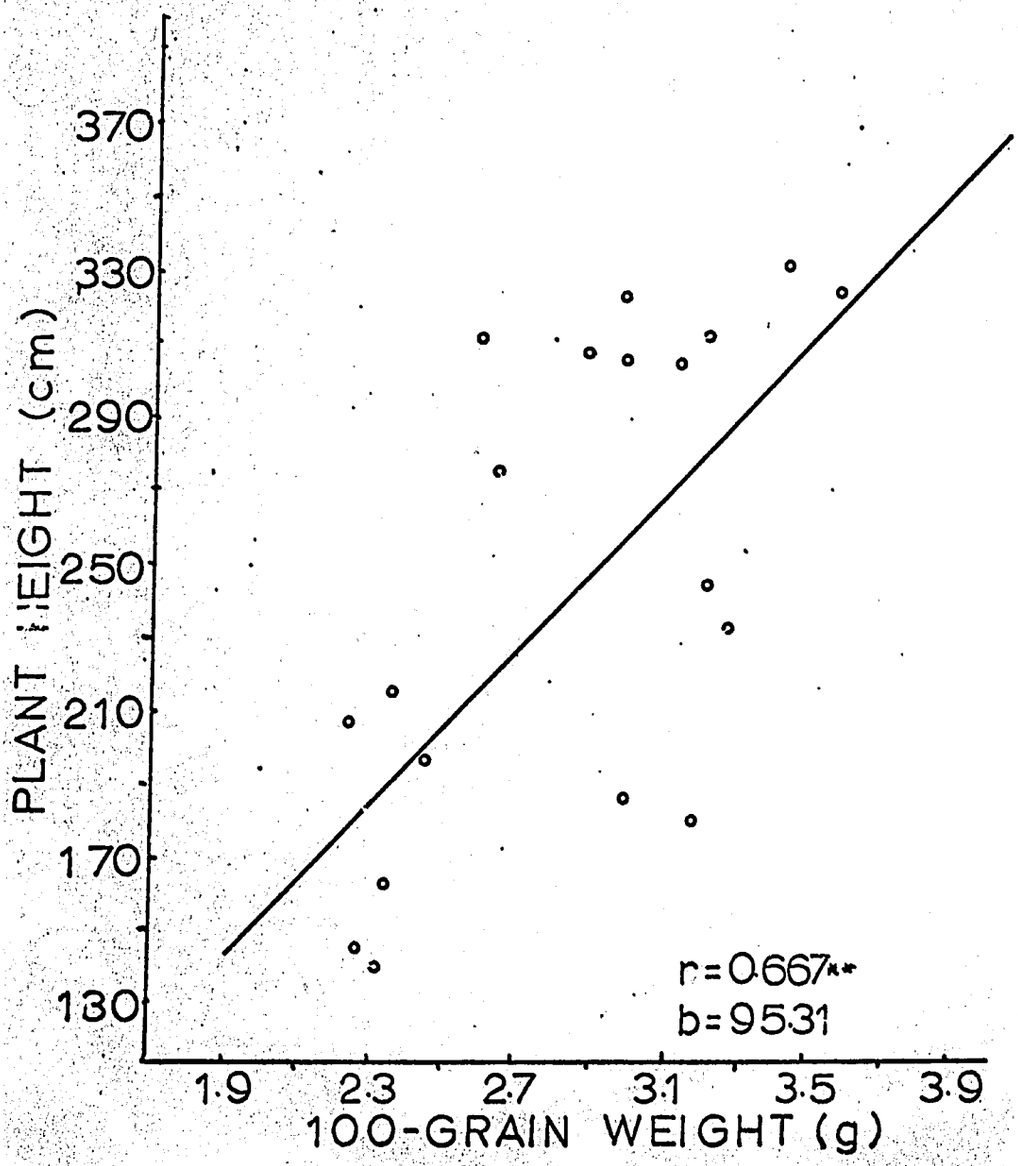


FIG 3. Number of grains/head compared to 100-grain weight of 19 F_1 groups.

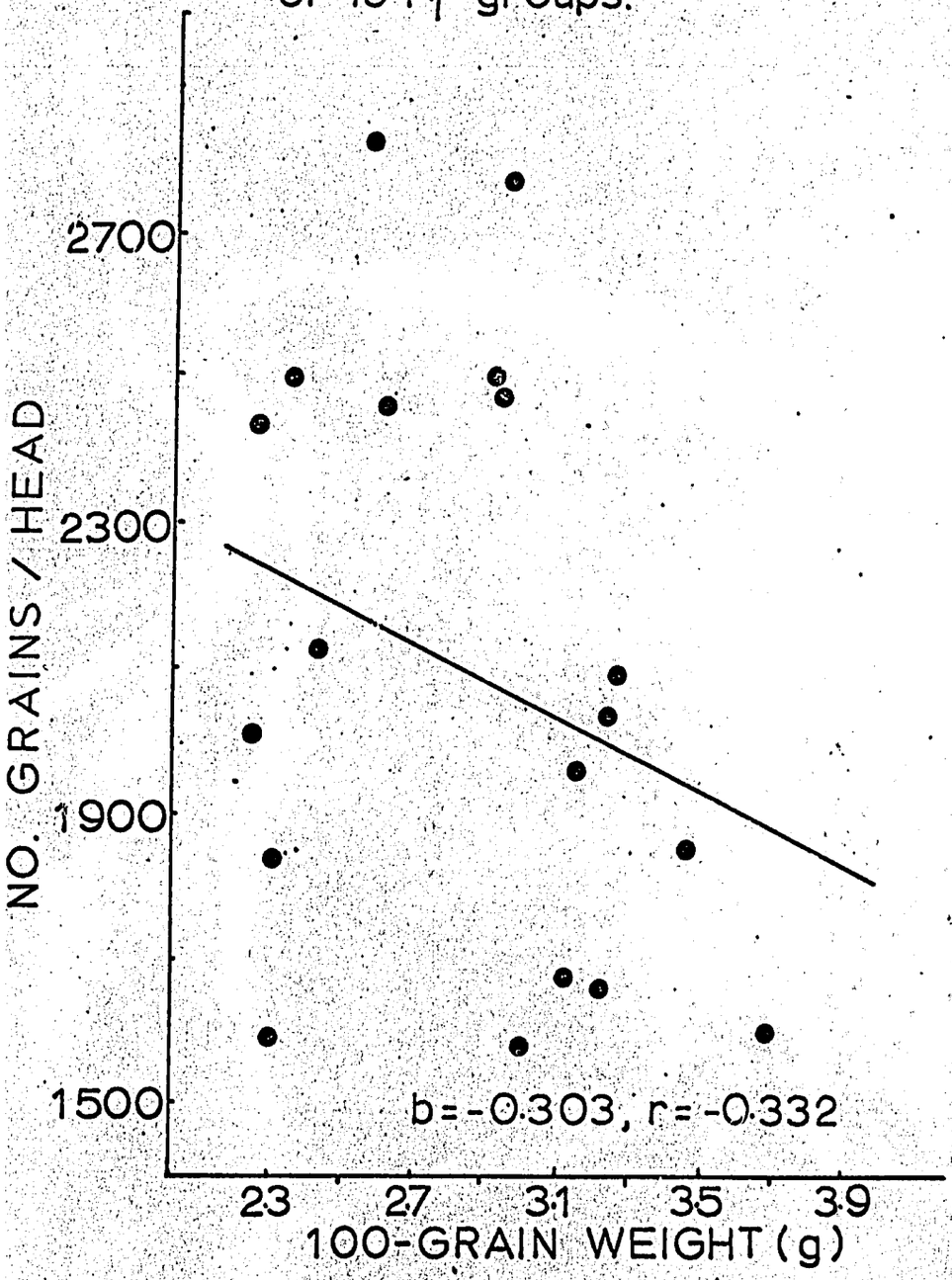


FIG 4. % protein as a function of 100-grain weight of 19 F_1 groups.

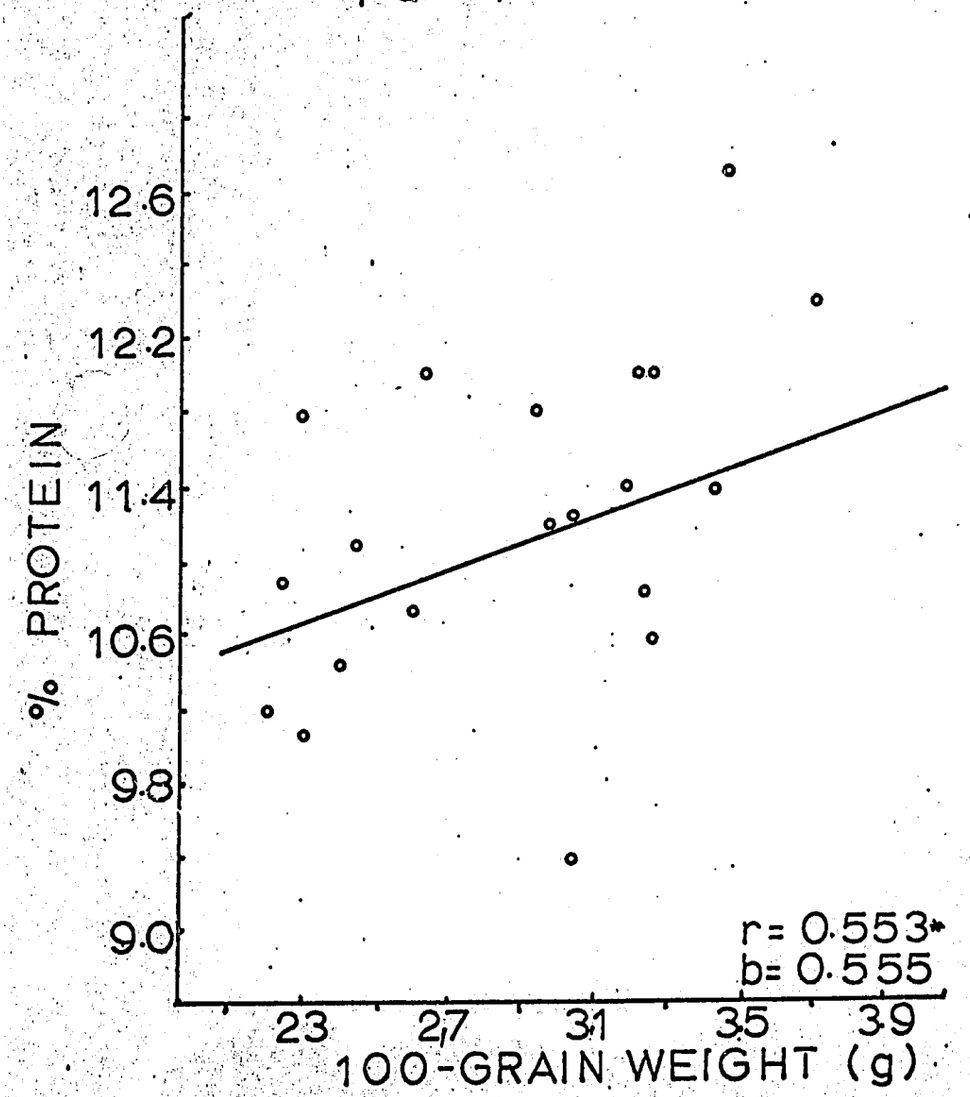
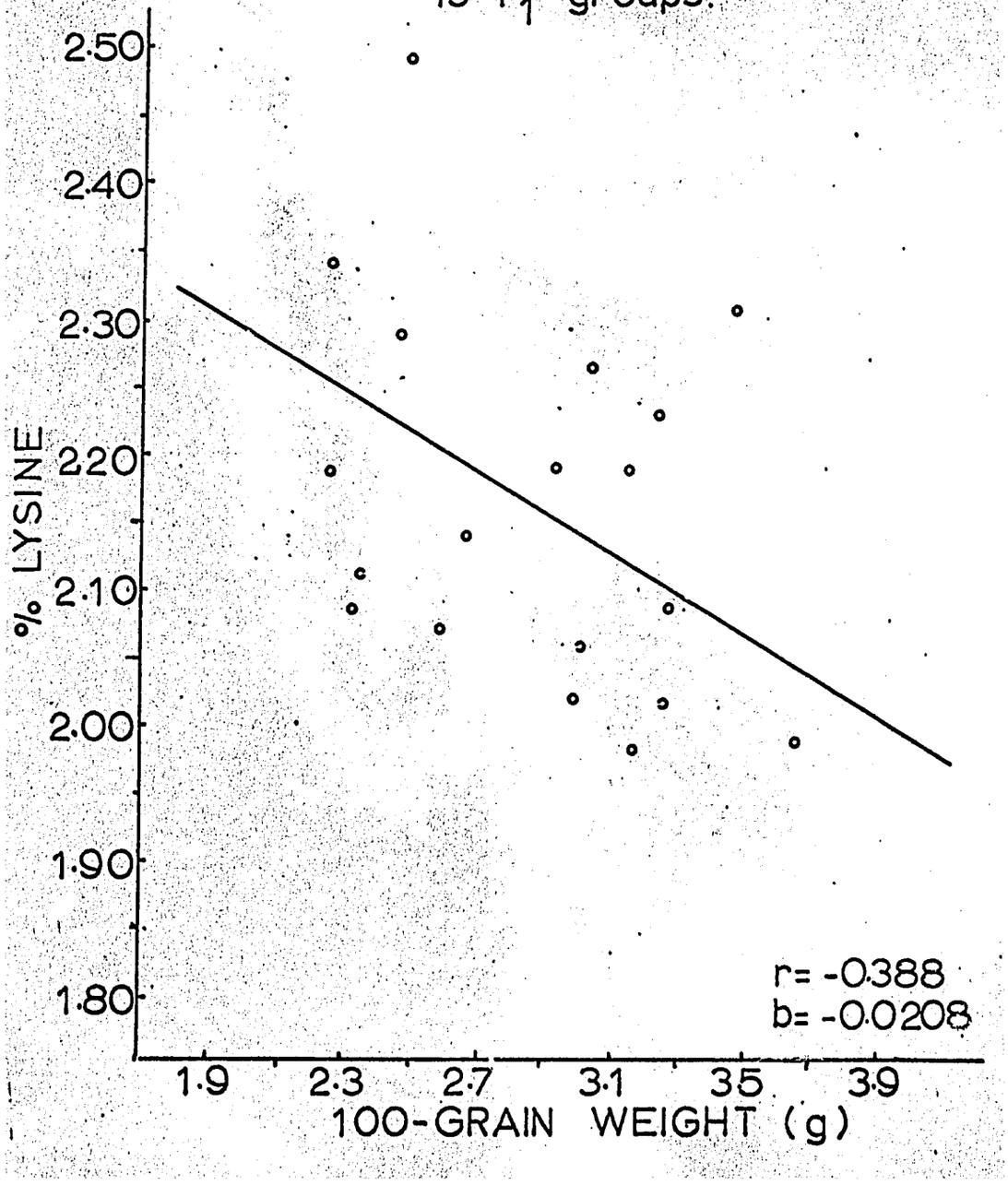


FIG 5. % lysine as a function of 100-grain weight of 19 F_1 groups.



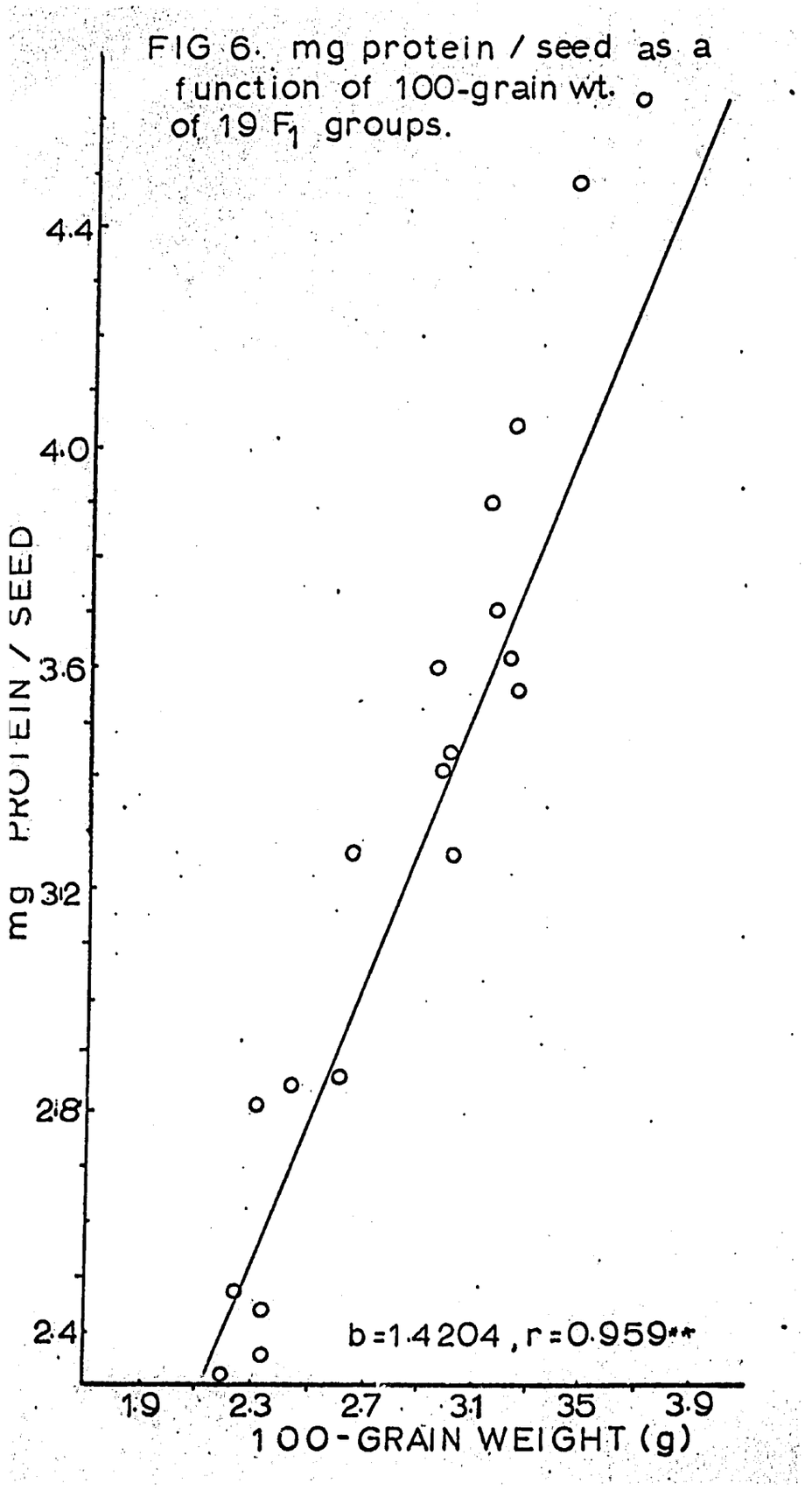


FIG 6. mg protein / seed as a function of 100-grain wt. of 19 F_1 groups.

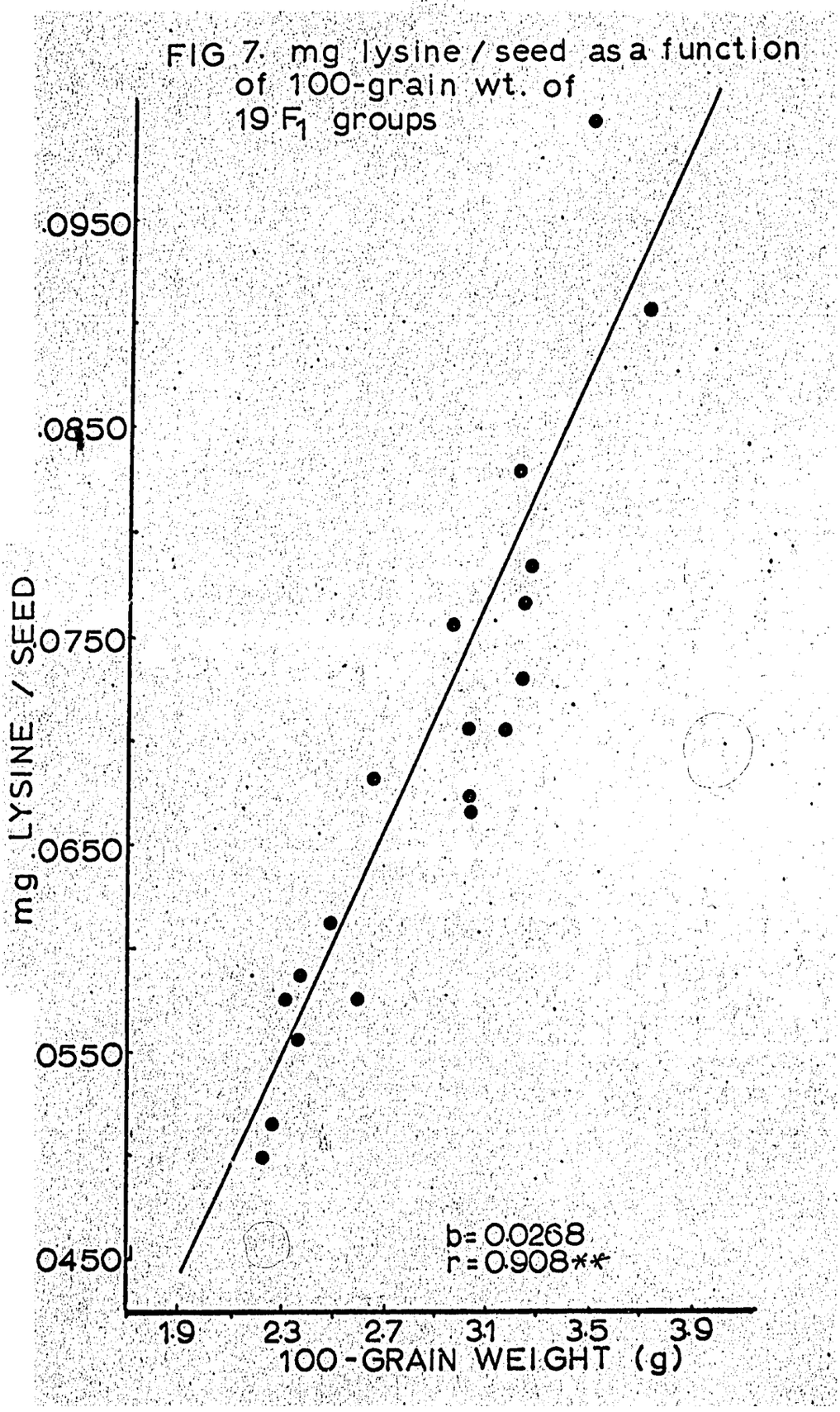


FIG 7. mg lysine / seed as a function of 100-grain wt. of 19 F_1 groups
.0950
.0850
.0750
.0650
.0550
.0450
mg LYSINE / SEED
b= 0.0268
r= 0.908**
1.9
2.3
2.7
3.1
3.5
3.9
100-GRAIN WEIGHT (g)

FIG 8. Grain yield / A. compared to mg protein / seed of 19 F_1 groups.

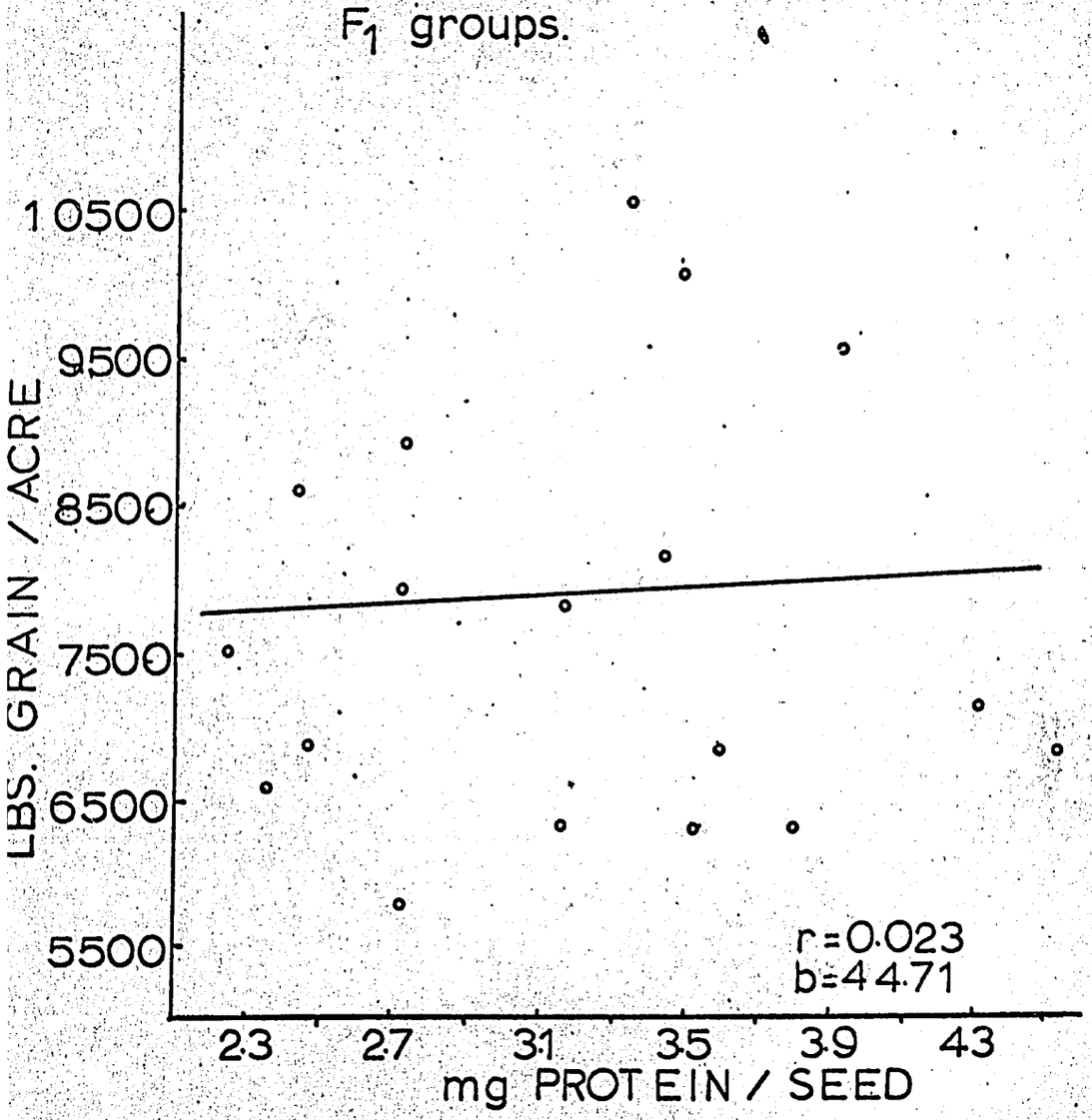


FIG 9. % protein as a function of mg protein / seed of 19 F groups.

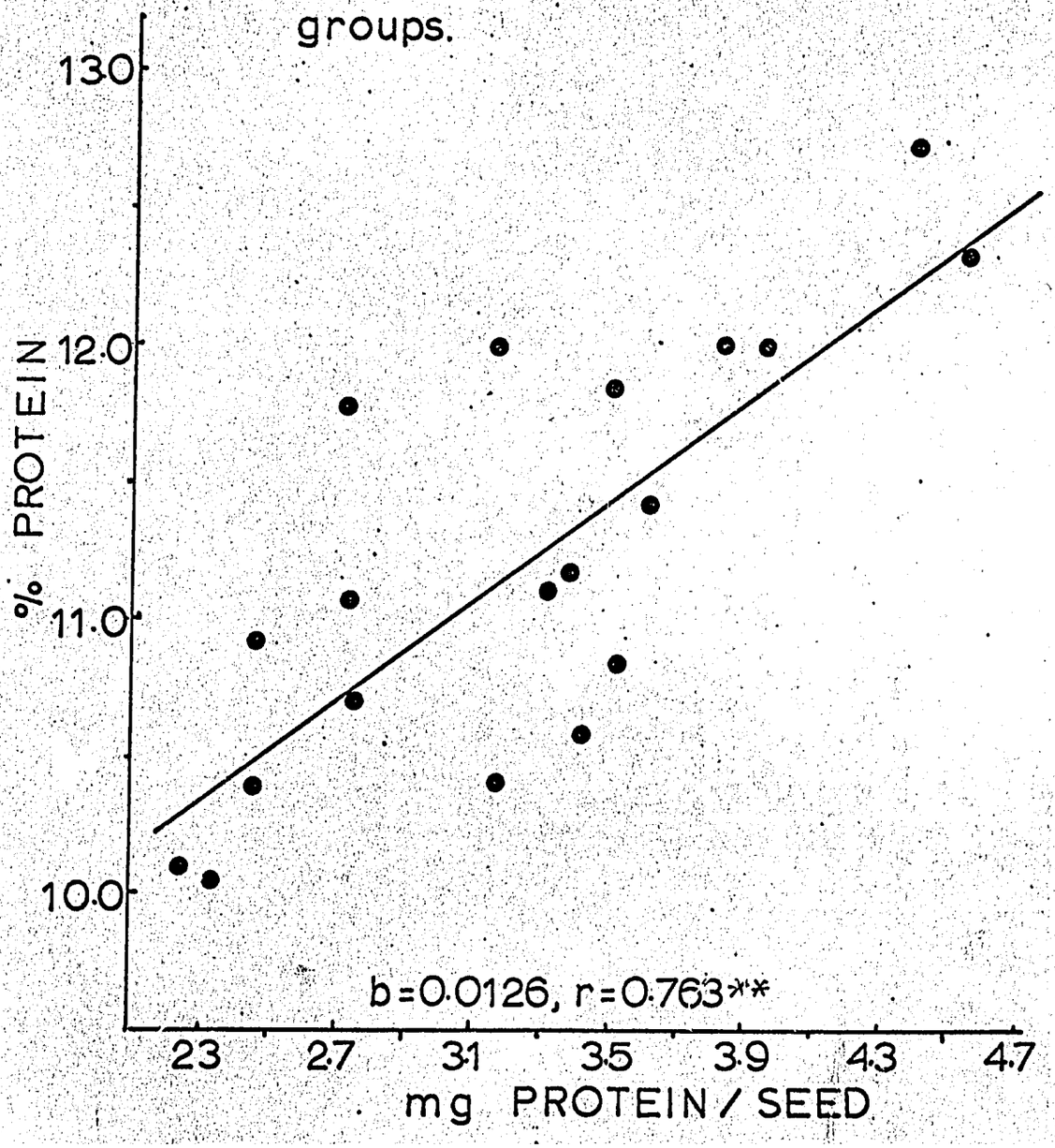


FIG 10. mg lysine / seed as a function of % protein of 19 F_1 groups.

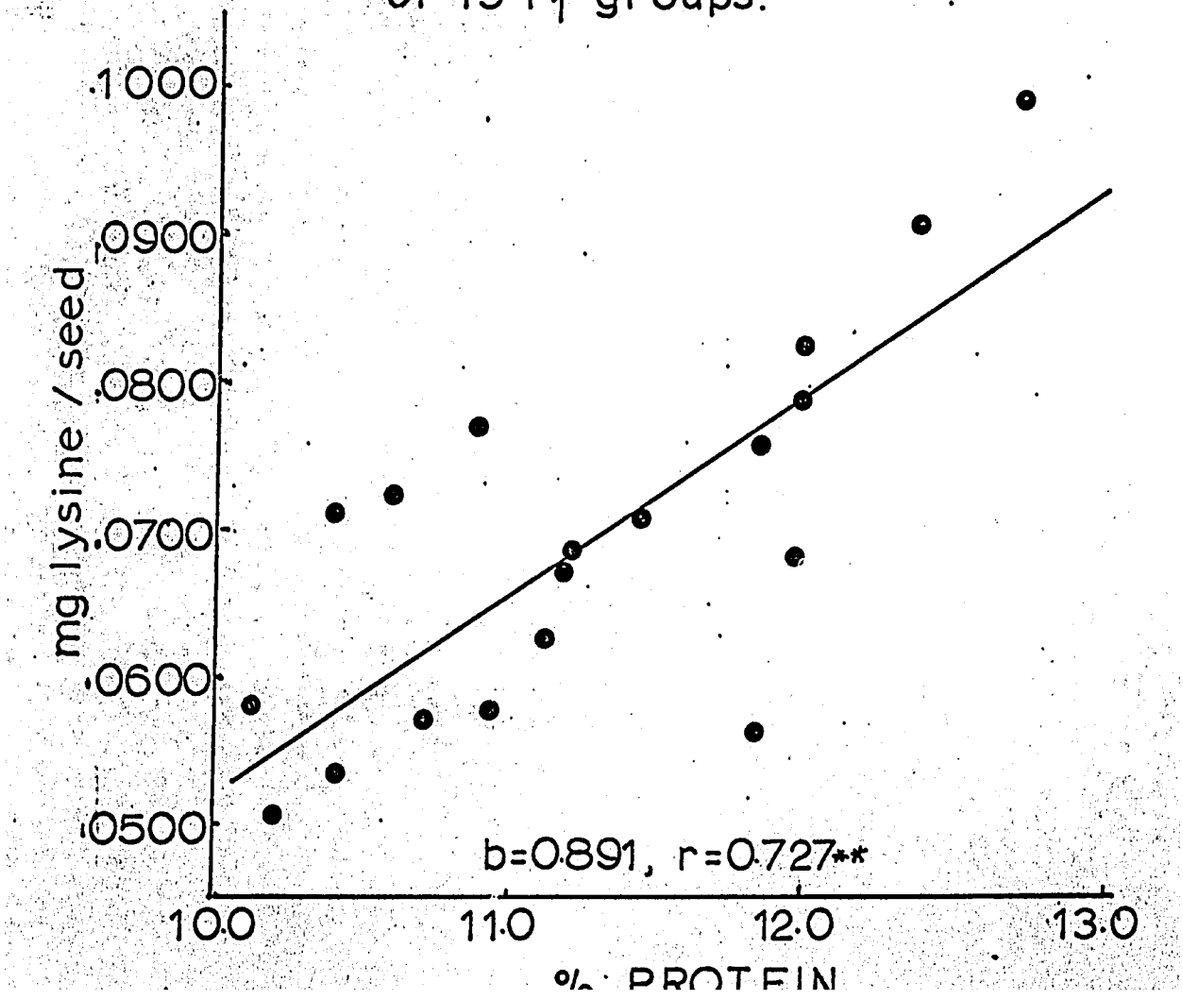
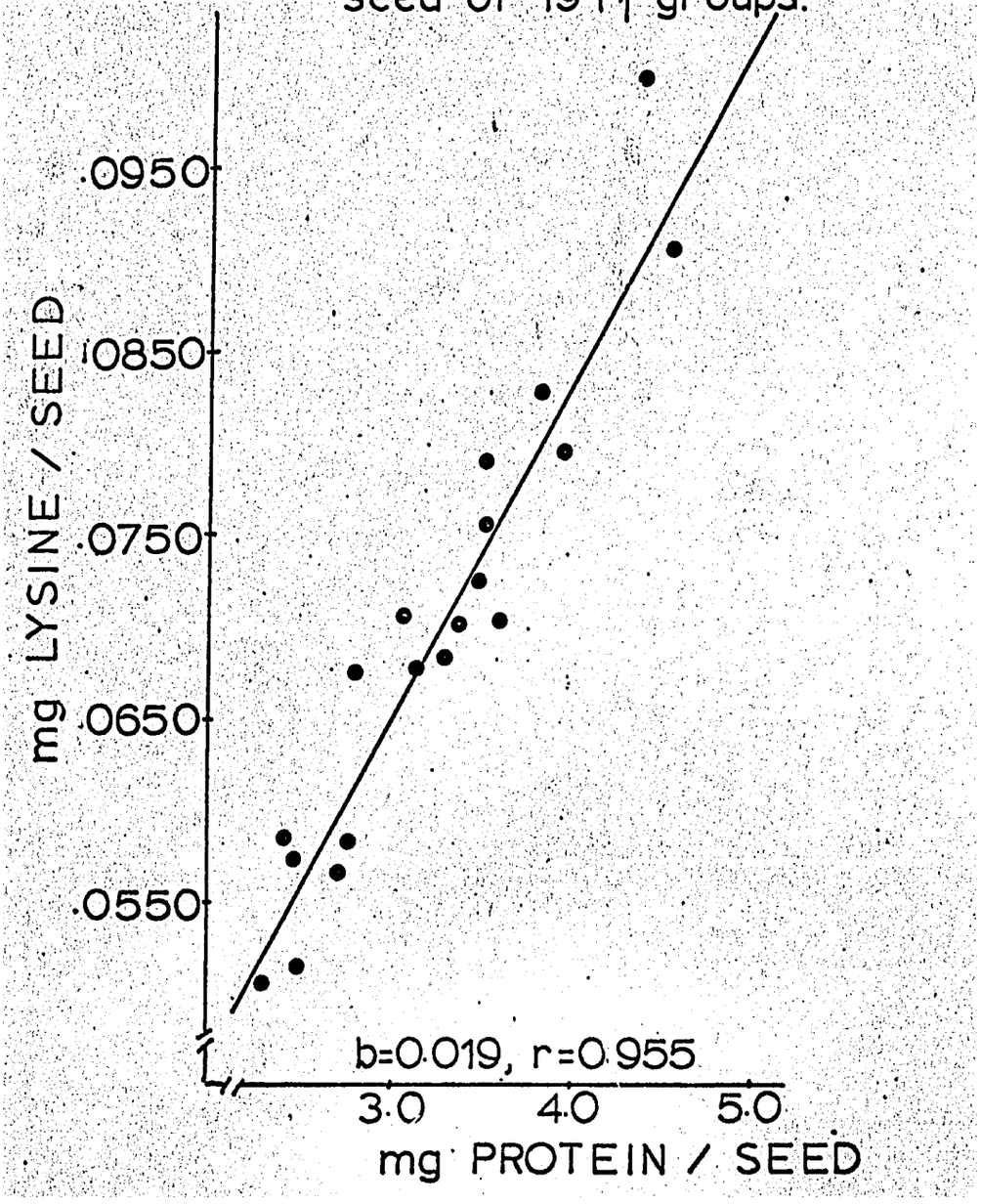


FIG 11. mg lysine / seed as a function of mg protein / seed of 19 F_1 groups.



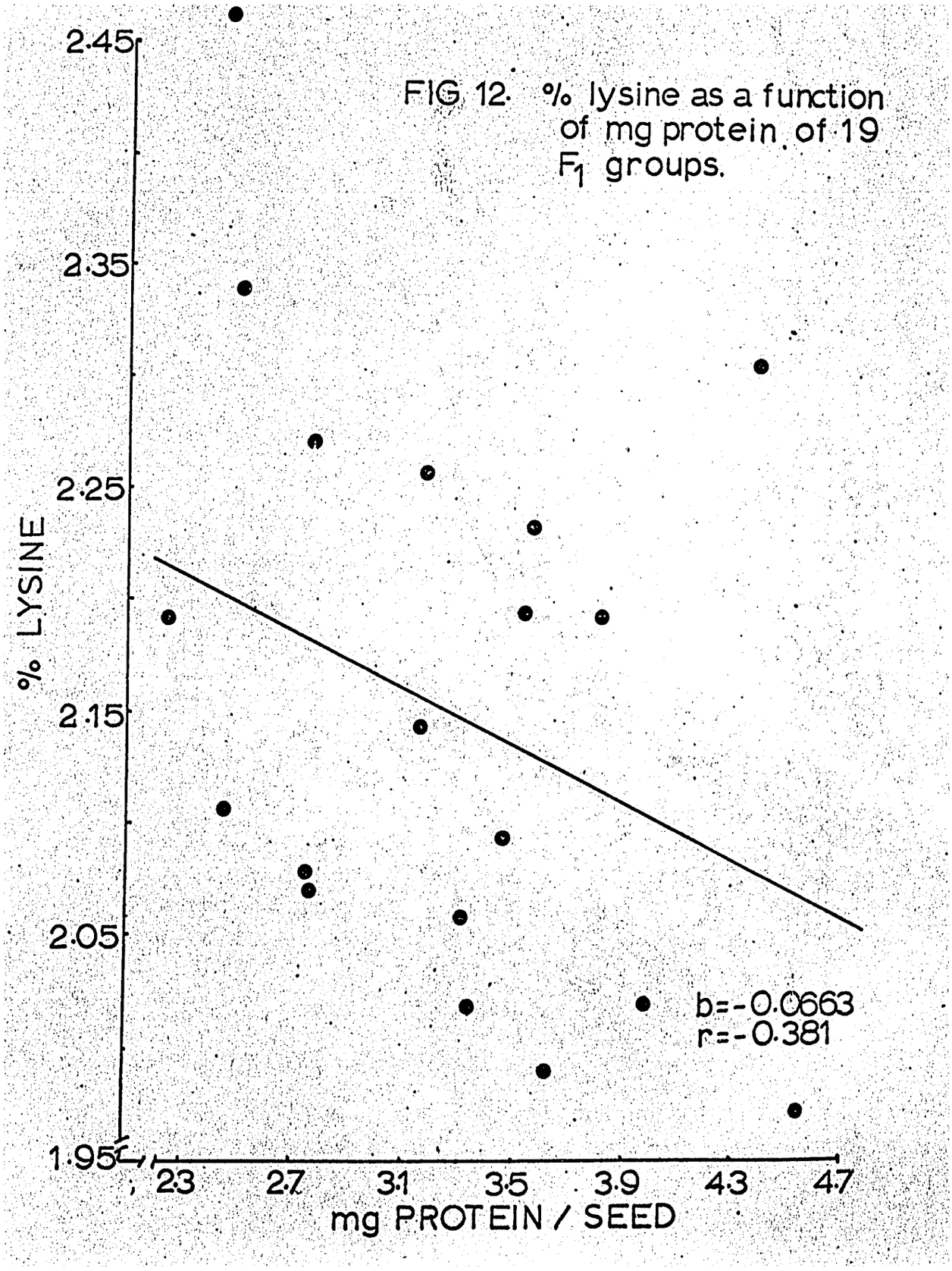


FIG 12. % lysine as a function of mg protein of 19 F_1 groups.

The relationship of percent protein to both percent lysine and of total content of lysine per seed is shown in Figures 11 and 12. Both diagrams are supported by intercharacter correlations from Tables 16 to 20. A positive relationship exists between lysine per seed and protein content, but a negative relationship exists for the association of percent lysine and percent protein.

Other research at Purdue has produced results in agreement with several of the observations from this study. Abifarin*, Bantayehu**, and Collins and Pickett (17) all found Martin to produce hybrids with the highest protein and lysine contents and reported the negative relationship between percent protein and percent lysine. All three studies also indicated that Redlan produced the highest yielding hybrids, but KS-24 was not included in any of the three programs.

Several additional intercharacter correlations from Tables 16 to 20 warrant inspection. Comparisons were limited to those which appeared in three or more instances of the five populations studied.

Early vigor was significantly correlated with lodging and plant height. It is possible that readings of early vigor were taken late enough (6 - 8 inches of seedling height) so that bias was introduced favoring the taller seedlings. Early vigor was also determined to be significantly negatively correlated in three of five evaluations with percent lysine and positively with grain yield.

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* Abifarin, A. O. 1969. Combining ability and heterosis for yield, protein, lysine and certain plant characters in 18 diverse inbreds and 56 hybrids in Sorghum bicolor (L.) Moench. Ph.D. Thesis, Purdue Univ.

** Bantayehu, G. 1971. Relationships of certain morphological characters with grain yield and quality of phenotypically diverse lines and hybrids in Sorghum bicolor (L.) Moench. Ph.D. Thesis, Purdue Univ.

Days to 50% bloom was often significantly associated with number of leaves, stem size, height, lodging, yield per head, and yield per acre. These correlations find support from the work of Abbe et. al. (1), Quinby (61), and Quinby and Schertz (67) who relate these features to siz of growing point. A negative correlation was indicated in three comparisons for days to 50% bloom and leaf angle, indicating that an upright leaf pattern was detected with the later genotypes. Loomis et. al. (46) noted that maize leaves shift to a more horizontal pattern after flowerin

Leaf number was significantly negatively associated with flag-leaf and third-leaf area, and positively with stem size, and lodging. Third-leaf area was significantly correlated with tillering, and tillering negatively with percent protein. It is difficult to interpret these associations.

Stem size was associated with yield per acre. This would relate to growing-point size as proposed by Abbe et. al. (1), Quinby (61), and Quinby and Schertz (67).

Percent lodging was significantly correlated with plant height, grain per head, yield per acre, and protein per seed. Many data from many crops support the association of yielding components with lodging. Percent lodging was also found to be negatively associated with percent lysine and head length in three instances of this study.

Plant height was often highly correlated with grain per head, 100-grain weight, yield, and protein and lysine per seed. It tended to be negatively associated at varying levels with percent lysine and head length, but positively with percent protein.

A fixed model was used in the analysis of data in this study. Even though many of the results obtained have been substantiated by work with other populations of sorghum, the interpretation of data is applicable only to the population involved herein.

SUMMARY AND CONCLUSIONS

An initial population of 65 diverse lines were selected in 1967 from the world collection of sorghum. An attempt was made to select for diversity of plant type in height, leaf areas, leaf angle, and maturity, in addition to selection of lines representing as many groups of sorghum as possible with the modified Snowden classification then in use.

Data on 19 male lines and their hybrids with four male sterile lines were considered in this study. The fertile or B counterpart line of the male sterile was used in place of the sterile line for parental comparison.

A total of 19 characters were measured or determined for this population. These were: early vigor, days to 50% bloom, number of leaves, flag-leaf area, third-leaf area, tillering, stem size, canopy cover, leaf angle, lodging, plant height, percent protein, percent lysine, head length, grain per head, 100-grain weight, yield per acre, milligrams of protein per seed, and milligrams of lysine per seed.

An analysis of variance for combining ability was determined for the F_1 data. Significant male or female mean squares were considered to represent general combining effects (GCA). This is equated with additive gene action, linear in effect, and utilized by the plant breeder through incorporation into pure line varieties. Significant male x female interaction is considered an expression of specific combining ability (SCA), due to dominance or epistatic effects and to be utilized or

exploited in production of hybrids. In this study male effects were highly significant for all 19 characters studied. Significant or highly significant female effects were determined for days to 50% bloom, plant height, head length, and milligrams of protein and lysine per seed. The SCA component, males x females, was significant or highly significant for early vigor, days to 50% bloom, leaf numbers, flag- and third-leaf areas, canopy cover, leaf angle, lodging, plant height, percent lysine, head length, threshed grain per head, and milligrams of protein per seed. Plant height and days to 50% bloom may be explained as dominance (intra-allelic series) action and it may be possible that allelic series exist for several of the other examples of SCA detected.

Intercharacter correlations were determined for all 19 characters. Comparisons pertaining to yield and quality factors were considered of primary importance.

Evaluation of Male Lines

Several of the male lines used appeared to have special merit as parent lines in hybrid combination.

For yield per acre, male 43 hybrids produced the most grain, followed by progeny of 34, 42, 38, and 36. In percent heterosis over the midparent, value, male 34 was highest (91.6%) followed by 43, 50, 42, and 33.

Males 30, 11, 42, 13 and 41 produced progeny high in milligrams of protein per seed. In ranking by percent heterosis over midparent values, male 13 exhibited 50.8% heterosis, followed by 11, 42, 43, and 20.

High levels of lysine per seed were produced by males 11, 30, 13, 42, and 20. Percent heterosis over midparent values showed male 13 at 52.4% highest, followed by 11, 30, 43, and 20.

Percent protein was substantially increased by males 11 and 13, while lysine percentage was increased slightly by males 34, 29, 33, and 11.

Evaluation of Female Lines

Hybrids with KS-24 and Martin averaged 81 days from planting to 50% bloom, CK-60 hybrids in 83 days, and Redlan hybrids in 84 days. For the quality factors of grain, Redlan hybrids averaged 3.14 mg of protein per seed while Martin hybrids were high at 3.41 mg. In terms of percent protein, CK-60 hybrids were the lowest at 10.8% to the high for Martin hybrids at 11.3%. Redlan hybrids were lowest in both percent lysine (2.06%) and mg of lysine per seed (0.639). The highest group of hybrids for lysine were those with KS-24 which averaged 2.29% and .0733 mg/seed.

The male sterile line KS-24 had not been used in sorghum investigation at Purdue before this study and appeared to possess unique potential. Abifarin*, Bantayehu**, and Collins and Pickett (17) indicated the superior yield potential of Redlan hybrids as well as the superior protein and lysine levels associated with hybrids of male sterile Martin. In the present study hybrids with KS-24 produced the most grain per acre, were second in protein percent and mg protein per seed, and highest in percent lysine and mg of lysine per seed. Hybrids tended to increase their total mg protein and mg lysine through seed weight increases in this study,

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* Abifarin, A. O. 1969. Combining ability and heterosis for yield, protein, lysine and certain plant characters in 18 diverse inbreds and 56 hybrids in Sorghum bicolor (L.) Moench. Ph.D. Thesis, Purdue Univ.

** Bantayehu, G. 1971. Relationships of certain morphological characters with grain yield and quality of phenotypically diverse lines and hybrids in Sorghum bicolor (L.) Moench. Ph.D. Thesis, Purdue Univ.

but hybrids of KS-24 averaged the smallest seed weight of the four sets of hybrids on plants that were 20 cm shorter. It appeared from this study that male sterile KS-24 possesses a rare combination of characters for use in a protein quality improvement program. KS-24 may be of interest not only for utilization in a hybrid program but the genetic mechanism controlling protein synthesis may be of value for developing varieties.

Intercharacter Association

Seed weight was highly correlated with plant height but not with grain yield per acre. Protein content, measured as mg/seed, remained relatively constant over yield per acre in this study. Derived data illustrated the negative relationship of seed weight and seed numbers per head which has been reported by other workers.

Several vegetative characteristics were found to have important associations with yield and quality factors in this population. Percent lodging was significantly correlated with plant height, amount of grain per head, yield per acre, and protein per seed, and was negatively associated with percent lysine and head length. In this study there was excessive lodging of tall material, but minimal lodging in the shorter lines. Perhaps lodging could be reduced while retaining the desirable aspects of tall material by selecting for medium heights. Since plant height was positively correlated with grams of grain per head, 100-grain weight, yield, percent protein, and mg of protein and mg of lysine per seed, it would appear that the merits of taller lines deserve special attention.

Prediction of F_1 Performance from Parental Performance

Low correlation coefficient was determined between percent protein of the parent lines with mean F_1 performance in this study. Percent lysine F_1 performance was only slightly correlated with parental lines, but 100-grain weight and mg protein and mg lysine per seed were correlated sufficiently to be useful if testing were not practicable since the confidence intervals determined are greater than most programs would prefer to assume. Grain yield was determined to be significantly correlated with female parent levels, but the estimated confidence interval is too large to permit utilization of the correlation.

The Usefulness of Measuring Protein and Lysine Content per Seed

All correlation coefficients indicated positive association of mg protein and mg lysine per seed with seed weight and with percent protein. Mg of protein per seed was essentially independent of grain yield per acre. If selection were based on mg protein per seed, then percent protein, seed size, and mg lysine/seed should all improve. Further analysis for percent lysine would be required to detect those unique genetic combinations which would possess above average levels of lysine.

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APPENDIX

Appendix Table 1A. Identification of male parent lines from initial selection. (Based on a modified Snowden classification.)

I. S. Number	Code No.	Group	Race *	Classification
				Subseries - Guineense I - B
3911	5	1	G	Roxburghii
2207	6	2	KC	Roxburghii - shallu
5871	7	3	GK	Conspicuum
3837	8	3		Conspicuum
8064	9	5	G	Margartiferum
				Subseries II - Nervosum
1216	10	8	KB	Nervosum - kaoliang
1220	11	8	K	Nervosum - kaoliang
3127	12	9	B	Nervosum - Broomcorn
				Subseries III - Bicoloria
0710	13	10	DC	Bicolor
0640	14	13		Dochna - Leoti
0637	15	13		Dochna - Leoti
2868	16	14		Dochna - Amber
0649	17	15		Dochna - Collier
6271	18	17		Dochna - Roxburghii
6341	19	20	B	Dochna - Durra
				Subseries IV - Caffra
0628	20	22		Caffrorum
3688	21	22s	DB	Caffrorum
3796	22	22	GD	Caffrorum

Appendix Table IA. Continued.

I. S. Number	Code No.	Group	Race.*	Classification
8231	23	23	GKC	Caffrorum - Darso
2862	24	24m	GC	Caffrorum - Birdproof
2227	25	25		Caffrorum - Roxburghii
2240	26	25		Caffrorum - Roxburghii
8205	27	31	C	Nigricans - Feterita
3530	28	32		Nigricans - Durra
3982	29	33	KC	Caudatum
7124	30	33	BC	Caudatum
2319	31	33s		Caudatum
2740	32	33s		Caudatum
0514	33	34s	KC	Caudatum - Kaura
7186	34	35	CG	Caudatum - Guineense
2760	35	38		Caudatum - Kafir
0132	36	38	D	do
0112	37	38		do
6198	38	38	DC	do
0121	39	38s	GD	do
0129	40	38s	CK	do
0867	41	38m	KC	do
8295	42	38s	C	do
8330	43	38s	C	do
2881	44	38s	GC	do

Appendix Table 1A. Continued.

I. S. Number	Code No.	Group	Race *	Classification
2643	45	40m	BK	Caudatum - Durra
				Subseries V - Durra
1387	46	45		Durra - Dochna
6445	47	46		Durra - Kafir
0504	48	48	D	Durra - Feterita/Kaura
1030	49	49	DC	Cernuum
0337	50	51	D	Subglabrascens - Milo
				Subseries VI - Grass Types 2n = 20
3301	51	52		Sudanense
7099	52	53	KD	Grass Grains
8305	54	unknown	GD	

* Based on a classification proposed by: Harlan, J. R. and J. M. J. de Wet. 1972. A simplified classification of cultivated sorghum. Crop Sci. 12:172-176.

Appendix Table 2A. Identification of male parent lines removed from further evaluation during 1969 test year.

I. S. Number	Code No.	Group	Reason for removal
0640	14	13	Excessive early-season lodging in F_1's
0637	15	13	do
2868	16	14	do
0649	17	15	do
6271	18	17	do
6341	19	20	do
2227	25	25	B-genotype
2240	26	25	do
3530	28	32	Excessive early season lodging in F_1's
2319	31	33s	do
0112	37	38	do
1387	46	45	do
6445	47	46	do
7099	52	53	do

Appendix Table 3a. Summary agronomic data of parent lines and hybrids by entries, averaged by replications.

Line Identification	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Head Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
KS-24 (B)	2.5	78	14	125	278	2.7	2.3	3.3	2.7	0	125	10.3	2.31	26	44	1.91	7429	1.97	.0455
Martin (B)	2.5	75	13	128	269	2.7	2.1	2.6	2.7	0	130	11.1	2.11	25	39	2.13	7.76	2.41	.0501
Redlan (B)	1.5	77	12	144	366	4.6	2.3	3.2	2.3	0	160	10.6	2.05	20	41	2.48	7011	2.62	.0539
CK-60 (B)	2.0	72	12	163	313	3.5	2.3	2.2	2.5	0	140	10.4	2.47	19	30	2.58	2864	2.69	.0663
7	2.0	68	10	192	317	2.5	1.0	1.0	2.7	0	130	11.9	2.11	27	31	2.01	6207	2.41	.0510
11	3.0	81	16	145	278	2.0	1.8	2.4	2.2	7	307	10.6	2.23	19	77	3.30	8167	3.50	.0781
13	4.0	77	13	161	303	3.7	1.8	3.5	2.7	3	252	11.3	2.13	19	29	2.14	5459	2.43	.0521
20	2.0	81	16	69	217	4.5	2.2	2.0	2.5	0	140	10.8	2.27	25	42	2.86	5686	3.10	.0697
22	2.0	88	18	83	262	3.0	2.1	3.5	2.3	0	152	10.1	2.44	28	46	2.73	6995	2.77	.0679
24	2.5	76	12	306	423	5.2	2.3	2.8	2.8	1	167	10.8	2.27	24	47	2.92	5936	3.15	.0716
29	2.0	90	14	98	325	3.6	2.2	2.5	2.8	0	130	10.7	2.34	26	26	1.77	4122	1.89	.0444
30	4.0	71	10	227	313	4.2	1.3	2.0	2.2	3	282	12.9	1.71	26	34	3.86	5803	5.00	.0854
33	2.0	97	16	118	404	3.0	2.5	3.3	1.3	0	122	13.4	2.03	31	32	2.65	4404	3.55	.0724
34	3.0	69	10	285	330	4.5	2.0	2.0	2.3	8	260	14.0	1.77	31	23	3.14	3745	4.50	.0794
36	3.0	79	11	368	382	4.6	2.3	4.5	2.0	0	122	13.0	1.86	21	28	2.10	6667	2.75	.0511
38	3.5	78	12	445	419	4.4	2.2	4.3	2.5	1	175	10.4	2.19	21	41	2.17	7099	2.42	.0533
40	2.5	68	10	175	275	4.6	1.5	3.0	2.5	0	120	11.4	2.27	20	24	1.96	7031	2.23	.0507
41	4.0	86	17	138	301	2.5	2.7	4.5	2.1	8	235	12.6	1.70	32	62	2.78	6645	3.58	.0610
42	3.0	91	16	110	248	4.4	2.8	4.2	1.5	0	190	12.3	2.20	13	46	2.64	6040	3.26	.0716
43	3.5	78	12	375	400	5.0	1.8	3.5	2.7	2	182	10.2	2.13	21	42	2.36	6016	2.41	.0513
45	3.0	76	13	100	319	2.8	2.0	3.0	2.3	7	222	11.3	2.23	19	57	3.23	6265	3.65	.0815
49	2.0	85	15	120	342	3.6	2.2	3.0	2.2	0	132	12.0	2.19	23	35	1.97	4937	236	.0516
50	3.0	86	15	117	295	4.0	2.2	2.6	1.5	1	142	12.8	2.03	15	26	2.35	2850	3.01	.0612

Appendix Table 3A. Continued.

Line Identification	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Head Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
KS-24 with:																			
7	1.5	70	11	225	359	3.7	2.0	1.6	3.0	0	127	12.2	2.16	27	36	2.27	5687	2.76	.0593
11	4.5	76	14	143	301	2.3	2.2	3.1	2.5	8	325	13.1	2.36	23	70	3.41	7358	4.45	.1047
13	3.5	77	14	143	252	3.5	2.0	3.3	2.6	7	292	11.7	2.74	25	51	3.09	6849	3.63	.0939
20	2.0	75	14	113	340	6.0	2.2	3.0	2.5	0	147	11.1	2.29	30	57	3.61	6456	4.03	.0921
22	3.0	79	16	141	337	5.4	2.1	3.7	2.6	0	160	10.1	2.48	29	42	2.55	5913	2.58	.0640
24	2.5	91	17	219	355	2.6	2.7	4.0	2.1	9	305	10.4	2.28	26	73	2.76	7409	2.88	.0658
29	2.5	71	13	181	398	4.5	2.3	3.0	3.0	0	142	10.9	2.42	27	41	2.40	6977	2.63	.0632
30	5.0	77	10	328	451	3.1	1.7	3.1	2.6	6	317	13.5	2.14	26	52	3.70	5953	4.99	.1068
33	3.0	81	14	162	326	2.8	2.5	4.7	1.8	0	140	11.4	2.41	31	49	2.43	7450	2.84	.0659
34	4.0	95	17	311	404	3.1	2.6	3.8	2.1	9	367	11.7	2.29	32	102	3.21	13755	3.78	.0855
36	4.5	81	12	635	530	3.5	2.7	4.5	2.7	2	182	11.0	2.28	26	63	2.59	9469	282	.0643
38	4.0	92	17	144	418	5.2	2.8	4.0	2.7	9	282	11.3	2.14	25	77	2.65	10466	3.00	.0644
40	5.0	78	11	476	469	4.0	2.3	4.5	2.3	1	172	10.8	2.14	24	60	2.07	8974	2.23	.0480
41	4.0	81	16	146	307	2.3	2.3	4.5	2.0	7	220	10.8	2.28	29	63	2.87	6997	3.11	.0710
42	4.0	82	17	115	299	3.1	2.3	3.2	2.2	9	295	11.6	2.09	20	68	3.04	8913	3.54	.0740
43	5.0	89	13	488	473	5.0	2.1	4.0	2.3	9	272	10.4	2.13	24	77	2.65	11712	2.76	.0589
45	3.5	74	13	199	367	4.6	2.3	3.2	2.5	4	217	10.6	2.31	23	72	3.39	8791	3.59	.0829
49	2.5	74	11	219	429	3.5	2.3	2.8	2.2	0	137	10.6	2.38	29	48	2.21	6582	2.33	.0555
50	3.5	94	17	165	356	3.5	2.5	4.5	2.0	9	240	12.1	2.17	19	72	2.57	8421	3.11	.0674
Martin with:																			
7	2.0	70	11	261	315	3.4	2.0	1.5	2.8	0	137	12.4	2.00	26	36	2.38	6302	2.95	.0590
11	4.0	78	15	130	335	2.3	1.8	2.5	2.8	7	320	13.8	2.27	24	74	3.46	8398	4.79	.1091
13	3.5	75	12	191	370	2.5	1.5	3.0	2.7	7	337	11.8	2.02	25	54	3.04	6022	3.60	.0724
20	3.5	70	13	212	311	4.6	2.2	3.5	3.0	1	182	10.7	242	30	47	3.16	5445	3.37	.0830

Appendix Table 3A. Continued.

Line Identi-fication	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
22	3.0	76	16	117	260	6.2	2.2	3.5	3.0	1	192	11.5	2.03	30	53	349	7341	4.02	.0812
24	5.0	90	15	258	469	4.0	2.3	4.2	2.8	8	335	12.1	1.87	27	69	2.76	7641	3.41	.0626
29	2.5	71	12	204	371	5.0	2.2	3.2	3.0	0	162	10.2	2.68	26	40	2.40	6584	2.45	.0655
30	4.5	80	12	339	403	3.2	2.0	3.5	2.6	7	320	12.4	2.02	25	48	3.51	5725	4.39	.0287
33	2.0	80	15	157	299	2.6	2.3	4.7	2.3	0	150	11.6	2.28	29	50	2.30	7938	2.65	.0506
34	4.5	91	14	246	349	2.5	2.2	3.8	2.0	9	340	13.8	1.99	30	56	3.21	8327	4.45	.0386
36	4.5	82	13	436	441	4.3	2.3	4.7	2.7	7	210	10.1	2.16	25	56	2.18	7770	2.20	.0475
38	4.0	91	17	146	322	4.7	2.3	3.8	2.3	9	297	10.8	2.02	22	66	2.48	8124	2.69	.0544
40	5.0	78	12	460	509	4.3	2.3	4.5	2.0	6	215	10.6	2.16	27	56	2.27	8260	2.39	.0517
41	3.5	77	16	125	321	3.5	2.3	4.0	2.8	9	247	13.0	1.82	30	64	3.27	6970	4.26	.0771
42	4.5	89	16	130	264	2.5	2.8	3.2	2.3	9	315	11.8	2.17	21	76	3.29	10793	3.90	.0346
43	4.5	91	17	139	300	2.5	2.7	3.7	2.3	9	327	13.1	1.90	21	80	3.33	12231	4.34	.0322
45	5.0	70	13	181	353	2.8	2.0	3.5	2.3	9	232	10.9	2.01	23	49	3.12	7257	3.41	.0527
49	2.5	76	12	223	388	4.1	2.3	3.3	3.0	0	142	11.0	2.59	27	45	2.09	6944	2.30	.0597
50	3.0	92	16	115	301	2.3	2.3	4.0	2.0	9	270	11.9	2.27	19	58	2.69	7197	3.20	.0726
Redlan with:																			
7	2.5	71	11	231	392	3.0	2.0	2.2	2.5	0	140	11.3	2.16	24	39	2.31	6283	2.63	.0567
11	4.0	79	15	125	239	1.8	2.1	2.8	2.5	8	337	13.2	2.05	22	58	3.55	5956	4.68	.0555
13	4.5	76	13	116	287	2.8	2.0	4.0	2.5	7	287	12.5	1.95	21	52	3.32	5382	4.16	.0311
20	3.0	79	17	103	280	4.4	2.1	3.7	2.6	0	195	10.0	2.33	28	58	3.04	6816	3.02	.0706
22	2.0	82	16	089	248	4.7	2.1	4.0	2.5	0	195	10.2	2.33	26	47	2.93	5375	2.99	.0699
24	4.5	91	15	130	329	4.8	2.7	3.7	2.3	5	277	11.5	1.92	26	94	3.23	9371	3.75	.0717
29	3.0	76	13	158	355	5.1	2.1	3.1	2.8	0	177	9.8	2.37	26	42	2.06	5939	2.02	.0480
30	4.5	84	11	263	447	3.1	1.7	2.8	2.0	6	332	11.9	1.78	24	67	3.74	7850	4.45	.0791
33	3.5	97	17	131	330	2.2	2.8	36	2.0	9	332	11.2	1.94	21	65	2.83	9952	3.19	.0616

Appendix Table 3A. Continued.

Line Identi-fication	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
34	3.5	91	16	165	293	3.3	2.5	4.7	1.7	0	150	10.5	2.38	27	41	2.04	6194	2.15	.0512
36	4.0	92	11	614	559	8.0	2.7	4.3	2.3	8	245	9.5	2.12	24	70	2.11	9828	2.00	.0425
38	3.5	93	17	123	272	4.0	2.5	4.0	2.5	9	337	10.0	2.02	23	94	2.64	10386	2.64	.0533
40	4.0	78	13	464	510	4.6	2.1	4.1	2.1	2	212	10.5	2.18	22	49	2.33	6167	2.34	.0510
41	3.5	82	16	120	310	3.8	2.3	4.5	2.3	9	250	11.4	1.76	30	79	3.37	8327	3.85	.0678
42	4.0	90	17	118	285	2.5	2.8	2.8	2.5	9	310	11.9	1.93	19	71	3.12	10437	3.71	.0715
43	3.5	90	13	339	414	4.3	2.6	3.6	2.1	8	292	9.8	2.08	23	72	2.91	9765	2.86	.0594
45	2.5	76	12	121	445	4.6	2.1	3.5	2.1	8	240	10.5	2.00	23	86	3.22	9128	3.39	.0677
49	2.5	77	13	141	327	4.5	2.1	3.8	2.0	0	152	10.7	2.14	26	48	2.35	7663	2.50	.0537
50	4.0	95	16	089	299	4.0	2.3	4.1	1.8	9	287	11.9	1.86	18	69	2.51	7859	3.01	.0557
CK-60 with:																			
7	2.0	71	10	239	330	3.0	2.0	1.3	2.7	0	135	11.1	2.02	26	36	2.28	5095	2.55	.0510
11	4.5	74	13	151	293	1.6	1.8	2.3	2.7	4	333	10.5	2.52	24	59	3.39	6940	3.56	.0898
13	3.5	76	12	226	283	2.5	2.1	2.8	2.3	5	265	11.9	2.08	23	55	3.18	7071	3.79	.0788
20	2.0	75	13	201	381	5.1	2.1	3.0	2.3	0	177	11.6	1.89	31	54	3.11	6631	3.66	.0680
22	1.5	80	15	124	311	6.5	2.5	3.7	2.1	0	185	9.7	2.22	28	51	3.15	6566	3.06	.0680
24	4.5	91	16	142	302	5.5	2.8	3.1	2.7	9	315	10.4	2.14	25	91	3.09	8034	3.22	.0692
29	2.5	71	12	211	411	5.0	2.1	2.8	2.5	0	165.	9.5	2.46	28	49	2.46	7266	2.32	.0576
30	4.5	75	11	288	438	2.5	1.8	2.8	2.6	7	317	11.2	2.02	26	67	3.80	7744	4.26	.0860
33	2.5	90	16	118	290	2.6	2.5	4.3	2.0	0	150	10.2	2.49	29	44	2.22	6595	2.28	.0566
34	4.0	99	16	114	302	2.1	2.5	3.0	1.7	9	412	11.0	2.11	33	93	3.28	12053	3.62	.0761

Appendix Table 3A. Continued.

Line Identi-fication	Early Vigor	Blooming	No. Leaves	Flag Area	Third Area	Tillering	Stem Size	Canopy	Leaf Angle	Lodging	Height	% Protein	% Lysine	Length	Grain/ Hd.	100 Grain Wt.	Yield/ Acre	Protein/ Seed	Lysine/ Seed
36	4.0	87	15	273	320	6.5	2.7	4.3	2.5	7	225	10.1	2.00	23	56	2.44	8621	2.46	.0492
38	5.0	91	17	128	287	4.3	2.5	3.6	2.5	9	217	10.3	2.17	23	57	2.60	6809	2.68	.0581
40	4.0	86	13	358	409	4.8	2.7	4.7	2.5	6	197	9.2	2.30	24	57	2.34	6716	2.16	.0493
41	3.0	79	15	130	289	4.8	2.5	4.3	2.3	9	230	10.3	2.05	28	44	3.13	4989	3.21	.0659
42	3.5	88	16	132	331	2.5	2.5	2.0	3.0	9	310	12.7	1.89	18	56	3.56	8124	4.55	.0853
43	4.5	91	16	147	293	4.3	2.3	3.5	2.1	9	320	11.4	1.99	23	67	3.05	8484	3.46	.0689
45	3.0	71	12	192	427	3.8	2.0	2.8	2.3	4	227	10.2	2.06	22	63	3.39	7900	3.45	.0713
49	2.5	77	12	212	357	4.0	2.1	4.0	2.5	0	140	11.3	2.23	27	44	2.[illegible]5	6682	2.77	.0620
50	3.5	91	17	123	298	4.3	2.5	2.8	2.1	9	282	12.0	2.25	19	63	2.60	7891	3.37	.0755

VITA

VITA

Greg Otto Hinze was born 19 March 1931 in Scottsbluff, Nebraska to Alfred and Marie Hinze, eldest of five children. He received his elementary education in Lyman, Nebraska public schools, his secondary education from Greeley, Colorado public schools.

He entered Colorado A & M College in the fall of 1951; short of graduation when he enlisted in the United States Air Force in September of 1954, he was permitted to return to finish degree requirements by "Operation Bootstrap". He was awarded a B. S. degree in General Agronomy in 1956. Upon his release from active duty in 1958 he returned to Colorado State University to begin graduate studies under Dr. W. H. Leonard, and earned a M. S. in Field Crops in June 1960. Following graduation he taught and conducted research in the Agronomy Department of CSU for one year before moving to Akron to assume research on dryland crops in eastern Colorado. He was granted a sabbatical leave by CSU in 1967 to work toward an advanced degree under Dr. R. C. Pickett at Purdue University.

He is a member of American Society of Agronomy, Crop Science Society of America, Western Society of Crop Science, Sigma Xi, and Akron Lions Club.

He and his wife, Judy, have three children.