RELATIONS OF KERNEL SIZE WITH OTHER AGRONOMIC CHARACTERS IN GRAIN SORGHUM

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Sorghum (Sorghum bicolor (L.) Moench) is a robust cereal, able to grow and produce under a wide range of climatic conditions. With respect to its different forms, sorghum is cultivated for its grain used as human food or as livestock feed; for its forage from grazing types or from silage types; for its panicle branches (brush) used in making brooms; for its syrup or sugar which can be accumulated in large amounts from the juice in the stalks; or also for the purple pigment (Anthocyanin) used in certain countries as dye. The importance of sorghum in the economy of the world is recognized by its vast distribution, mass production, and varied utilization.

Sorghum is used as human food for many people of Africa, India, China, and other Far East countries. In the United States of America, sorghum is cultivated commercially and is used mainly as feed for livestock.

Sorghum improvement has been largely neglected compared with that of corn, wheat, and rice. Much of the agronomic and genetic improvement that has contributed to the development of modern pest resistant, quick-maturing, high-yielding, dwarf or semi-dwarf varieties and hybrids can be traced to the efforts of a relatively small number of agronomists who devoted their lifetimes to sorghum. Some of these agronomists are: Conner, Karper, Quinby, and Stephens of Texas;

Sieglinger of Oklahoma; Swanson of Kansas; Webster of Nebraska; Franzke of South Dakota; Martin, Ball, and Vinal of USDA Agricultural Research Service; and a few others in the United States, India, and other countries.

Sorghum is widely variable in almost all plant characters, including those associated with yield. This variability has been reported by several workers. All growth and developmental processes of any plant are governed by its genotype and the environmental conditions. Yield is conditioned by several components, which in turn are affected by internal and external processes.

Early efforts of sorghum breeders were directed toward testing introduced and local varieties, and selection of the well adapted, high yielding ones. At present the objectives of sorghum improvement are quite numerous and include: earlier maturity, improved palatibility and digestibility of the grain, improved forage quality, pest resistance, resistance to drought, resistance to cold temperature, and high yield. Considering the large number of these characters, variability within the species becomes a necessity. Hybridization has been used to create this variability within which selection of important characters can be made for later incorporation into a recurrent variety. Hybrids are of great importance for increasing yield. It is apparent that no great increase in yield was achieved in sorghum until hybrid vigor was utilized.

Hybrid vigor or heterosis is frequently defined as the increased vigor of the F_1 hybrid over its parents. There is some evidence that heterosis in sorghum is manifested more in grain production than in stover production (35). Heterosis is thought to result from the combined action and interaction of allelic and nonallelic factors and is usually closely and positively correlated with heterozygosity. If the relationship between heterosis and heterozygosity is linear, dominant gene action is indicated.

Kernel size is one of the important components characterizing yield. However, only a few studies have been made to establish its correlation to yield. Since kernel size is important in grain crop development, more information on its relation to yield and yield components would be helpful in grain crop breeding, not only for yield, but also for other kernel characteristics such as chemical composition.

The main objective of this research was to study kernel size and its relationship with yield and yield components in two crosses of grain sorghum. Another object of the present study was to determine whether kernel size could be increased while maintaining or increasing yield.

CHAPTER II

LITERATURE REVIEW

Relationships Among Kernel Size and Other Agronomic Characters

Most of the sorghum improvement work has been devoted to some of the following objectives: earlier maturity, white or yellow palatable grain, dwarf types, insect resistance, disease resistance, improved forage quality, and resistance to drought, cold, and heat. Some of these improvements should result in increased yield. However, the greatest progress in the improvement of sorghum by selection and hybridization has not been in incresed yield, but in developing varieties than can be harvested and cultivated more easily and economically (31). Sorghum breeding is being conducted now in India, China, Africa, the USSR, U.S.A., and in other countries with the main objective to increase yield under local conditions.

Yield, the increase in dry matter with time, is usually said to be conditioned by several characters. These agronomic characters are sometimes called yield components. Kernel size is one of these components. Therefore, it seems reasonable for a breeder to consider kernel size in a breeding program with the objective of increasing yield. Kernel size has been reported to be negatively correlated with yield.

In 1963, Quinby (35) studying the manifestations of hybrid vigor in sorghum, pointed out that heterosis in sorghum is characterized by earlier blooming, more tillering, greater height, and greater yield of grain and forage. He considered this increase in grain production due to heterosis to be the result of kernels per plant rather than an increase in size of kernels. Larger kernels is probably a manifestation of heterosis but, in his study, the most vigorous hybrids produced so many more kernels per plant that the kernels did not exceed the kernel size of the male parent.

Blum (5) compared nine grain sorghum hybrids with their parental lines in a field experiment on the manifestation of heterosis in grain production per panicle and each of the panicle weight components (number of whorls per panicle, number of branches per whorl, number of grains per branch, and weight per grain). Of all panicle weight components, a significant effect of heterosis (superiority over the best parent) was found only in the number of grains per branch, and mostly at the lower branches within the panicle. It was indicated that weight per grain and number of grains per panicle were negatively associated. The results demonstrated that of all panicle weight components, the most consistent and outstanding effect of heterosis was manifested in the number of grains per branch.

Simple correlation coefficients between the weight per grain and the number of grains per panicle were -0.009 and -0.433 in hybrids and parents, respectively (5). It was demonstrated that the weight per grain becomes further negatively associated with intra-panicle grain density, as grain density increases.

It seems therefore, that phenotypic effects of weight per grain and number of grains per panicle are negatively associated and that the strength of association depends on the magnitude of each of the traits.

Kirby and Atkins (23) in their study on the heterotic response for vegetative and mature plant characters in grain sorghum, investigated inter-character correlations among 24 F_1 grain sorghum hybrids. They found that grain yield was positively and significantly correlated only with the number of grains per head.

Martin (30) in 1928, in his study of plant characters and yield in grain sorghums, pointed out that the yields of fields of grain sorghums are more closely correlated with the number of heads per acre than with the size of head or weight of grain per head. He stated that the correlation between the number of heads per acre and both the weight per bushel of grain and the average size of heads was either negative or not significant in the varieties studied. The size or plumpness of kernels of a given variety was correlated with weight per bushel but not with yield per acre.

Kohle in 1951 (22) studying the correlations of grain and plant characters of Indian sorghum found that the greater the plant height, number of internodes, stem circumference and length, thickness and weight of ear, the greater the yield of grain and fodder. The characters studied varied considerably within each variety.

Liang, Overley, and Casady (25) in an estimation of genotypic and phenotypic correlations among 12 characters in segregating populations and in pure lines of grain sorghum, found that grain yield was positively and significantly correlated with head weight, kernel number, half-bloom date, and leaf number, but negatively correlated with germination percentage and protein percentage. The inverse relationships between kernel weight and kernel number, and between kernel weight and head number per plant may arise from developmentally induced relationships or be genetically dependent. They considered head weight and half-bloom date to be the best indicators of yield, while germination percentage may be of value as an indicator for protein content. Magnitudes of the estimates of expected progress in improving yield by selecting characters other than yield appear to be greater than those for protein. Investigations on the interrelationships among dry weight of panicles, threshing percentage and grain yield were made in sorghum yield trials at four sites during three years (3). The conclusion was that weights of unthreshed panicles may be useful as a selection criterion for relative grain yield among a group of hybrids. The variability of grain percentage of the panicle among hybrids, sites, and years indicated that the use of a standard threshing percentage to estimate grain yields from weights of unthreshed panicles would not be practical because the estimation procedure tended to overestimate the grain yield.

Grain crops other than sorghum were submitted to similar studies on agronomic characters by many other workers.

Hsu and Walton (18) studied relationships between yield, yield components, and morphological characters in spring wheat by computing simple correlation coefficients on a plot mean basis among 13 characters considered as well as partial correlation and regression coefficients (Factor Analysis). They found that the simple correlations among yield per plant and three primary components (number of ears per plant, number of kernels per ear, and 1000-kernel weight) were consistent for the trials in the greenhouse and in the field. Correlations between yield per plant and 1000-kernel weight were not significant as indicated by the partial regression analysis. They stated that plant varieties may have the same yield but have it as a result of different yield components and if yield is held constant, negative correlations among the components are to be expected. In this study, a negative correlation between ear number and 1000-kernel weight was found. Ear number per plant was the most important component.

In 1973, Sage (41) investigating the expression of heterosis for yield in restored F_1 wheat hybrids and its interactions with seeding rate and kernel size found that the extent of heterosis for yield and two yield components was small and was not affected by seeding rate in one trial. In an adjacent trial, he found that the extent of heterosis for yield in three hybrids was affected by kernel size. Another study by Bremner, Eckersall and Scott (6) on the relative importance of embryo and endosperm size in causing the effects associated with size in wheat revealed that embryo size had a negligible effect on growth, while endosperm size was shown to have a considerable effect. The influence of neither embryo size nor endosperm size appeared to be in any way modified by depth of planting. There was a suggestion that the relationship between kernel size and plant size is governed by the amount of reserve material present in seed.

In a study of correlation among kernel characteristics of 41 varieties of pearl-millet (14), the varieties were classed into four groups on the basis of grain weights, grain size, and relative density of grains and into six groups on the basis of water absorption. It was found that grain weight was significantly and negatively correlated with its size and relative density. Size and relative density accounted for 4% of the grain weight variance, and size and water absorption variables accounted for 33% of the variance. Another correlation study of some plant characters with yield in T-55 bajara <u>Pennisetum typhoides</u> Pers.

(32) gave evidence that grain yield was positively and significantly correlated with plant height, weight of ear, weight of grain per ear and 1000-grain weight.

In these studies on the relationships among some important agronomic characters with yield it was observed that correlations (negative and positive) among yield components are widespread among the major crop plants, particularly under various kinds of environmental stress. The correlations are believed to be developmental rather than genetic per se (1), and are postulated to be caused by genetically independent components, developing in a sequential pattern, that are free to vary in response to either: 1) a limited constant input of metabolites, or 2) an oscillatory input of these substances such that input is limited at critical stages in the developmental sequence. Also, discrepancies in the relative importance of yield components might be explained by plant type characteristics.

Kernel size is not to be taken as only a component of grain yield. It is also important in some other areas of plant breeding. Thus, Jones and Sieglinger (21) in a study of the waxy gene on grain yields of sorghum pointed out that the starchy genotype was superior in yield by about 10%; and that 1000-kernel weight (character that is often taken as kernel size) and test weight per bushel were both higher in the starchy genotype than in the waxy. There was evidence that the chemical development of the waxy endosperm was arrested just short of reaching its full expression which would result in starchy endosperm. Here again they stated that this might be responsible for the lower yield and smaller kernel. Chakravorty (8) in 1967 reported on protein content in relation to size of Jowar grains. Data are given on

1000-grain weight and grain protein content of 42 sorghum varieties and hybrids. Grains of the same size from different cultivars contained different protein contents. In a given variety, protein contents were higher in large, well developed grains than in small, underdeveloped grains, but the reverse held for hybrids. In 1971, Aycock and Bauman (4), studied the effect of selection for relative kernel weight in heterozygous opaque-2 and floury-2 maize populations with the criterium being the relative weights of the mutant and translucent kernels on segregating selfed ears. When compared, the two populations responded similarly. The weight ratio of mutant to translucent kernels increased. They attributed this response to a trend of decreasing weight of translucent kernels rather than an increase in weight of mutant kernel types. Whole kernel protein values for the mutant kernel types did not change; but a significant linear decrease in lysine expressed as percent of protein resulted. Lysine levels were still adequate, especially in the opaque-2 populations. It is suggested that consideration also be given to kernel weight in a selection program of this type.

In 1971, Jellum and Powell (20) studied the fatty acid composition of oil from pearl millet kernels. They reported that in one variety the proportion (range of 2.3 to 5.8%) of linolenic acid of total oil increased consistently as kernel size decreased.

The Genetic Nature of Characters in Sorghum

Yield is said to be the result of the interraction of genotype with its environment. Thus, in one sense, all genes that affect the development of the plant influence its yield.

Sorghum is a tropical species that can be grown in temperate zones because mutation at one or more of the four maturity gene loci allow early floral initiation (36). Tropical varieties are dominant at locus 1 and usually at the other three loci also. Temperate zone varieties are recessive at locus 1; or, if dominant at locus 1, are recessive at either locus 2 or 4. The expression of the four genes is influenced by environment. There is a positive correlation between duration of growth and plant size. Sorghum breeders shortened duration of growth and stature and made sorghum more suitable to be harvested mechanically, but did not increase yielding capacity until cytoplasmic male-sterility was found and hybrid vigor was utilized.

In 1968, Malm (29) reported the use of exotic germplasm in grain sorghum. In this study eight fertility restorer lines developed from African introductions were crossed with four male sterile lines to produce 32 hybrids. These 32 hybrids plus four check hybrids were evaluated for yield, kernel size, kernel density, and various quality characteristics. The four male steriles (A-lines) were chosen as a genetic base for evaluating general combining ability.

A combined statistical analysis of the data revealed that nearly all interactions with years were highly significant (29). The data reported indicated that large-seeded parents produced the highest yielding hybrids, however, all sets of exotic hybrids produced larger seeds than the checks. Some exotic hybrids produced 50% more protein than the checks. Considerable variations in starch, fat, and fiber showed that a great potential exists for improving the quality of grain sorghum. Malm (29) further reported that genetic diversity appears to be the key to obtaining hybrid vigor because the crosses involved geographically and genetically diverse parents which produced high yielding hybrids. He stated that the potential value of using introductions in a plant breeding program to obtain new sources of germplasm should not be overlooked.

A positive regression of yield on maturity was reported by Dalton in 1967 (11). His work provided evidence which demonstrated an inherent positive high yield to late maturity relationship among grain sorghum hybrids when growing conditions are favorable. The pooled regression for yield per day from planting to maturity for 20 hybrids was 222.44 ± 70.06 kg/ha/day. Much of the variation in hybrid yields was due to their differences in maturity. These results showed that for accurate evaluations of sorghum yields the effect of maturity must be considered in detecting the more productive hybrids at all maturity levels. Reddy and Liang in 1971 (40) estimated plant-to-plant genetic variability for F_2 grain yield from 10 sorghum populations. They reported that the higher yielding parents tended to produce greater genetic variability in F_2 with larger population means, possibly because of the accumulation of desirable genes. The genetic variability in most populations did not seem to be sufficient for effective selection as evidenced by the ratio between estimated genetic and environmental variances. They suggested the incorporation of diverse exotic material in the current germplasm. They stated that using heritability without examining the magnitudes of genetic and environmental variance components may be misleading in certain cases.

In 1973, Quinby (37) reported some information on the genetic control of flowering and growth in sorghum with inferences that a higher level of gibberellin caused greater growth of the panicle and more elongation of the rachis and rachilla in different genotypes studied.

Rao et al. (39) reported the results of a genetic analysis of some exotic x Indian crosses in sorghum. In this work the nature of association between days to half-bloom, plant height, and yield was examined in productive advanced generation selections and compared with the dwarf-early and tall-late parents and their crosses. They reported that the correlations, both phenotypic and genotypic, were considerable in the parental groups and the within-group crosses, while they were low or negligible in intermediate selections and in the between-group crosses. The direct and indirect contributions of days to half-bloom to yield were more pronounced than those of the plant height. The direct effects were also of higher magnitude in the parental groups and their within-group crosses. The vital role played by days to half-bloom in determining the yield potential was brought out. They stated that undesirable linkages and similar associations get dissipated in the intermediate selections from crosses between extreme forms. Thus, the intermediate selections, as revealed by correlations and path coefficients have little or no association between yield components but have good yielding potential and represent intermediate productive peaks.

Chapman and McNeal (9) studied the gene action for yield components and plant height in a spring wheat cross. Means and variances for the parental, F_1, F_2, and single backcross generations were used to analyze quantitative genetic variation. In both 1967 and 1968, epistatic effects were not significant in the inheritance of the number of spikelets and kernel weight. Additive gene action had the greatest effect on number of spikelets. Both additive and dominant types of gene action influenced kernel weight. When epistatic effects were significant, the metrical value of the F_1 markedly exceeded the value of the higher parent.

The action of genes controlling quantitative characters was described by the use of gene models by Anderson and Kempthorne (2). They cited Fisher who constructed a gene model which included dominance at a single locus. Fisher stated that there may be a deviation from the single additive effects between loci, similar to dominance at one locus, if more than one locus affected a given character. He called the deviation epistacy. Anderson and Kempthorne (2) also cited Fisher, Immer and Tedin who used this gene model to describe the actions of any number of genes on a given character assuming there was no epistacy. Griffing as cited by Anderson and Kempthorne (2) introduced an epistatic parameter into a model. The factorial gene model which is an adaptation of the factorial model used in the design of experiments is developed and applied to problems in quantitative inheritance.

Heritability of Characters

The heritabilities of characters in grain sorghum are used for determining the volume of the character as a means of selecting for yield.

The word heritability can be defined as the level of transmissibility of a particular character from one generation to another. Heritability is of great importance in plant breeding. Knowing the inheritance of a chracter, the breeder will be able to calculate how much variation in a segregating population is due to genetic differences and how much to environment. Thus, the transmission of the given character to a current variety will be easier.

Heritability estimates and gene effects for agronomic traits in grain sorghum were studied by Liang and Walter in 1968 (27). In this work they reported that heritabilities of yield and kernel number were lower than those of head weight, kernel weight, stalk diameter, and half-blooming. Heritabilities of plant height and germination percentage were of a still higher order. They also reported that the magnitude of heritabilities varied greatly among crosses for yield, head weight and kernel number. Additive gene effects appeared to make a minor contribution to the heritability of grain yield, head weight, kernel weight and kernel number but seemed to be more important for other traits. In the heritabilities of most of the traits, dominant gene effects seemed to make a major contribution. Among the three types of epistatic gene effects they found that additive x additive and dominance x dominance were the most important.

Liang, Reddy and Dayton (26) studied heterosis, inbreeding depression, and heritability estimates in a systematic series of grain sorghum genotypes. Ten sets, each consisting of two pure lines and their F_1, F_2, and BC_1 generations were studied at two sites over two years. They reported as the result of this investigation that grain yield showed the highest heterosis and also the greatest inbreeding depression. Narrow-sense heritability estimates for the F_2 generation varied among sets. Estimates for days to first flower, height, and kernel weight were relatively high, while that for grain yield was low. Expected genetic advance in F_3 yield under selection was higher than actual advance for most sets, suggesting epistasis.

Voigt, Gardner, and Webster in 1966 (45) investigated a large-seeded variety of sorghum and a small-seeded variety, their F_1 and F_2 cross generations, and the two first backcrosses to gain a better understanding of how kernel size is inherited and to assess the possibility of increasing kernel size through selection.

A preliminary study indicated that a 300-kernel sample from each plant would give adequate precision. On the basic data from the population means and variances, they concluded that all populations were approximately normally distributed on the original scale and that transformation to $\sqrt{y-2}$ caused the large-seeded parent to depart from normality but eliminated the correlation between means and variances. They reported that gene action appeared to be almost entirely additive. Evidence for dominance or epistasis as an important contributor to kernel size was lacking. They found that a minimum of three or four genetic factors or blocks of genes, primarily additive in their effect, appear to control kernel size. Heritability for kernel size was estimated to be 60% indicating that considerable progress could be made in shifting mean kernel size by selecting and re-combining large-seeded F_2 plants.

Fanous, Weibel, and Morrison in 1971 (13) in a study of quantitative inheritance of some head and seed characteristics in sorghum, used five crosses of sorghum in the F_2 and the F_3 generations. They reached the conclusion that heritability estimates of 100-kernel weight were higher in some crosses than others. The relative magnitudes of expected genetic advance expressed as a percentage of the mean for 100-kernel weight would suggest that not too much progress under early generation selection should be expected, particularly if selection is based on individual plants. They found that genotypic correlation estimates of 100-kernel weight and each of head length, seed branch length, and node number per head were generally small.

Relatively large negative estimates were obtained between 100-seed weight and head length and between 100-seed weight and seed-branch length in cross 3. Estimates of genotypic correlation for 100-seed weight and head length and 100-seed weight and node number per head were relatively large and positive in cross 5, but not in other crosses. They concluded that in cross 5, selection for head length should be effective in increasing 100-kernel weight, cross 5 being 'OK 8' x 'Woodward Big Head', a cross of small x large kernels.

Genotype by enviornment interaction effects for grain yield, protein, lysine, oil, and seed weight, of sorghum were investigated in 1972 by Schaffert, Oswalt, and Pickett (43). They reported that the genotype x year x locality interaction was significant for all variables except lysine as a percentage of protein. The genotype x locality interaction was significant for everything apart from grain, protein, and lysine yields, percentage of lysine in the sample and percentage of oil. The genotype x year interaction was significant for all variables except percentage protein, lysine (as a percentage of the sample), and plant height. Number of days to flowering was negatively correlated with percentage protein and positively correlated with lysine (as a percentage of protein). Percentage of protein was negatively correlated with lysine (as a percentage of protein) and positively correlated with percentage oil, seed weight, and lysine (as a percentage of the sample).

In 1967, Liang (24) reported a diallel analysis of 12 agronomic characters. With a few exceptions, general and specific combining ability interacted with locality significantly for all the characters.

Selection for Agronomic Characters

So far not one of the yield components has been identified as a good selection index for yield of grain or forage if taken alone. However, some studies have been made to establish specific roles of a given character in sorghum breeding.

In 1971, Wright and Major (42) compared heavy and light weight seed selections of Blue Panicgrass Panicum antidotale Retz for shoot elongation and production of dry matter. They found that selections with heavy seed weight showed the highest growth potential during all developmental stages. When compared with light seed-weight selections, performance was not variable among selections of each seed weight category. Relative to the original food reserves of the seed, the pattern of growth was similar for both seed-weight categories. They stated that the major role of seed food reserves was during the first six days of germination and seedling growth.

Vichitr in 1968 (44) studied the effects of mass selection for quantitative traits in sorghum. He reported heritability estimates of seed size, plant height and flowering date to be 20, 16, and 28% respectively. Selection for seed size and plant height was reported to be effective up to the seventh generation. Seed size was the most stable character in all environments studied and flowering date was the most sensitive to environmental fluctuations. Intermediate seed size was the optimum. With respect to plant vigor, any deviation from the average value for the base population brought about a reduction in vigor.

Work was planned to study the effects of autoploidy on a number of agronomically important characters, with special reference to yield components and crude protein content (28). The total number of grains per head is one of the primary components of yield which is not only determined by fertility, but also by the size of the head. An equally important primary component of yield is the number of productive heads which is determined by numerous factors, including germination efficiency and stand and tillering ability. In this study, grain size was the only primary component of yield responding positively to autoploidy. It was pointed out that increased grain size, however, failed to cancel the effects of reduced head production and grain number such that tetraploid yields remained far below those of the corresponding diploids. There was in fact a negative correlation between grain size and yield in advanced tetraploids. Increased grain size as such has no initial significance in tetraploid sorghum improvement unless it is favorably associated with other components of yield.

Phadnis, Tayyeb, and Ghawghawe (34) evaluating better foundation seed parents for use in sorghum hybrid production programs reported that the shining yellow grain of MS 22-5-16, which is dominant, and the fact that this line gave large grains when crossed with a small-grained restorer, made it the better parent in the production of hybrid grains.

Large kernels of a plant species generally have been shown to have greater seedling vigor than small seeds of the same species. This same relationship usually occurs when comparing species or genera, but with a lower correlation (16). In general, the closer the genetic background of compared lines, the higher the correlation between seed weight and seedling vigor.

In all the works that have been done so far, kernel size and yield correlations were very low or simply negative.

CHAPTER III

MATERIALS AND METHODS

The experimental material was composed of two F_2 populations having a common female parent. The crosses were made in the greenhouse at the Agronomy farm of Oklahoma State University in 1972 as follows:

Cross #1: (R-K x Korgi^2-E-1) x (BOK 24 x WBH)

Cross #2: (R-K x Korgi^2-E-1) x (AOK 24 x ROKY 43-1-1-1)

Some of the general characteristics of the parental lines involved in the study are given below:

R-K x Korgi^2-E-1: The R-K represents a selection from the cross 'Redlan' x 'Kaura' where Redlan was an Oklahoma variety and Kaura was a yellow endosperm introduction from Nigeria. 'Korgi' is also a yellow endosperm introduction from Nigeria. Both Kaura and Korgi had large kernel size. The selection from the complex cross which was used in this study had purple plant color, large corneous yellow endosperm kernels, and awnless lemmas.

BOK 24 x WBH: The 'BOK 24' line is a 4-dwarf selection from the cross B Redlan^4 x SA 3002-1-E1 where the SA 3002-1 is a 4-dwarf Day x Sooner milo derivative. 'WBH' represents a breeding selection, Woodward Big Head, derived from a cross involving Cyto #1, a male sterile plant of milo origin, and Kaura. This male parent of cross #1 had purple plant color, large white kernels with yellow endosperm, and awnless lemmas.

AOK 24 x ROKY 43-1-1-1: AOK 24 was the cytoplasmic-genetic male-sterile form of BOK 24. 'ROKY 43' was selected from the complex cross Cyto #1-Korgi-3-2 x (A Redlan - Kaura 5-7 x Cyto #12 - Kaura-10-2-1) where 'Cyto #12' was a male-sterile plant of kafir origin. This male parent of cross #2 had purple plant color, medium sized red kernels with yellow endosperm, and awnless lemmas. All parents involved in making the F_1's of these F_2 populations were considered to be homozygous diploid for the characters studied.

The parents and their F_1's were grown in the field at the Perkins Agronomy Research Station in 1972. Observations were made during the growing season, and measurements were recorded. The female parent had the largest kernels and BOK 24 x WBH had larger kernels than AOK 24 x ROKY 43-1-1-1. Because of these differences, cross #1 was considered a cross of large x large sized kernels while cross #2 was a cross of large x medium sized kernels.

The F_2 plants studied in this paper were coded 73-3228 for cross #1 and 73-3259 for cross #2. For purposes of brevity and more appropriate terminology the groups of plants from the two F_2 crosses will be identified as F_2 population-1 for cross #1 and F_2 population-2 for cross #2 throughout this paper. The study of the relationships between kernel size and other agronomic characters in F_2 populations was conducted at the Perkins Agronomy Research Station and in the Sorghum Breeding Laboratory at Oklahoma State University in 1973-74. Both F_2 populations were sown in a single 4-row plot on June 15, 1973 with a tractor-drawn two-row cone-type nursery plot planter in rows 25 feet long. The rows were thinned about 15 days after the seedlings emerged leaving approximately two plants per foot. The heads of all plants were covered with kraft paper bags treated with sevin. The bags prevented outcrossing and attack by insects. Since the bags were dated and placed on the heads the day before blooming started, they also served to establish onset of anthesis.

The following pre-harvest observations were recorded:

1. Days-to-bloom. The number of days from planting to anthesis.

2. Height. Distance in inches from the ground level to the tip of the panicle.

The following post-harvest observations were recorded:

1. Grain weight. Grains from individual panicles were weighed after threshing and the weight expressed in grams.

2. Kernel number. Total number of kernels for each head calculated using grain weight and 100-kernel weight.

3. Kernel size. Grains from individual heads were screened using screens of 6/64, 7/64, 8/64, 9/64, 10/64, 11/64, 12/64, and 13/64 inch round openings. The size of grains of a given head was determined by the screen that held the majority of the gains from the head.

4. 100-kernel weight. Weight in grams of 100 kernels taken from the grains representing the kernel size of the given panicle. Data were obtained for 157 plants of the F_2 population-1 and 178 plants of the F_2 population-2. Data collected for each plant were punched on I.B.M. cards so that all statistical analyses were made by computer using statistical analysis systems designed and implemented by Anthony James Barr and James Howard Goodnight.

The means, sums of squares, standard deviations, variances, and coefficients of variation were calculated for all characters in both

F_2 populations, and for the characters within each kernel-size.

The distributions of all individual variables and all variables versus kernel size were plotted for each F_2 population. Simple correlation coefficients of kernel size versus other variables and between variables within a given kernel size were calculated for both F_2 populations.

CHAPTER IV

RESULTS AND DISCUSSION

The results are presented in the following order: 1) frequency distributions of the characters studied for the two F_2 populations; 2) variabilities of the individual characters; and 3) correlation coefficients among characters of the two F_2 populations. The characters were analyzed in the following order: kernel-size, 100-kernel weight, grain weight, kernel number, days-to-bloom, and height. As already mentioned no height data were obtained for the F_2 population-2.

The average kernel size, 100-kernel weight, grain weight, days-to-bloom, and height for the parents and F_1's of the two F_2 populations are given on Table I. The common female parent in each of the two crosses had the largest kernel size, and the male parent for cross #1 had larger kernels than the male parent for cross #2. Among the parents the male parent of cross #1 had the heaviest grain weight and tallest plants with the longest period to bloom. The F_1 of cross #1 had larger kernel size, higher 100-kernel weight, higher grain weight, more days-to-bloom and was taller than the F_1 of cross #2.

Frequency Distributions

The frequency histograms of kernel size of the two F_2 populations are presented in Figure 1. The distribution showed a higher frequency of grains of size 10/64 inch for both F_2 populations. There were,

TABLE I

CHARACTERISTICS OF THE PARENTS AND F_1'S

Characters / Parents and F_1's	Average Height (Inch)	Days-to-Bloom	Average Kernel Size (/64 inch)	Average Grain Weight (gram)	Average 100-Kernel Weight (gram)
R-K x Korgi^2-E-1 ♀	38	57	12	23.38	5.23
BOK 24 x WBH ♂	39	58	11	34.96	3.16
AOK 24 x ROKY 43-1 ♂	31	53	8	24.2	2.14
F_1 of Cross #1	49	58	11	57.8	3.67
F_1 of Cross #2	38.4	50	10	50.8	3.15

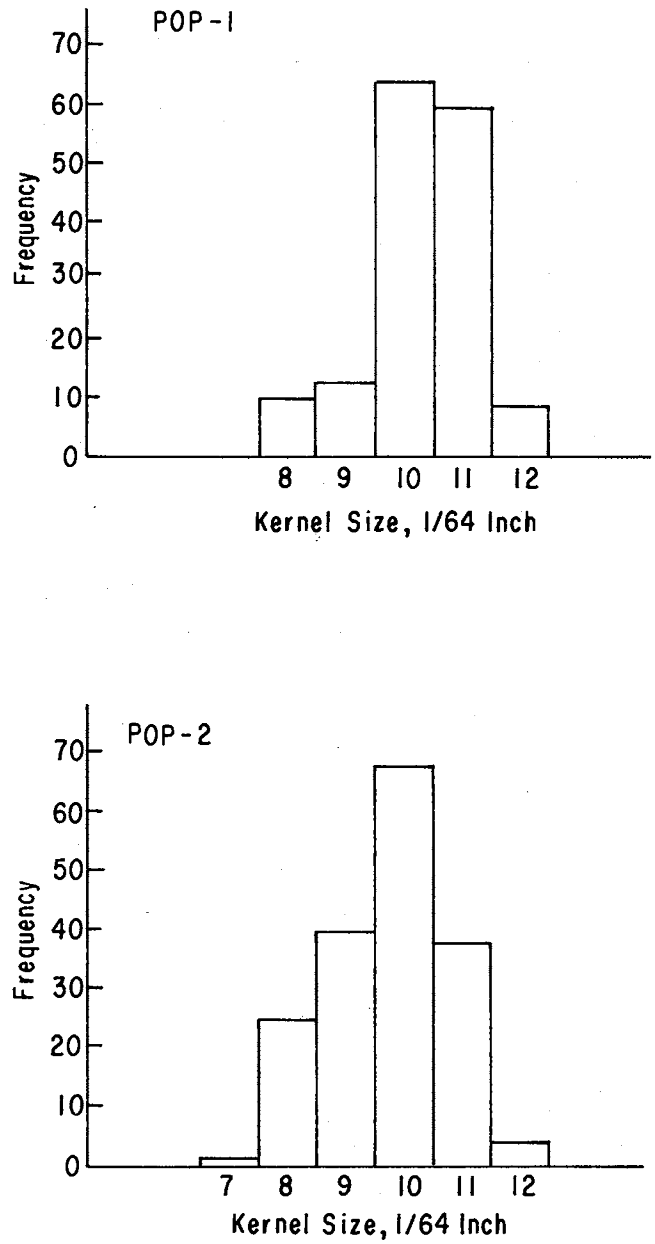

Figure 1. Frequency Distributions of Kernel Size

however, considerably more plants with a kernel size of 11/64 inch in population-1 than in population-2.

For 100-kernel weight Figure 2 showed a wide distribution in both F_2 populations. The class interval of 2.9-3.3 grams with an average of 3.1 grams for 100-kernel weight contained the most plants in both F_2 populations, but population-1 had more plants in the heavier weight classes. The distributions of 100-kernel weight versus kernel size (Figure 3) showed a higher 100-kernel weight for the larger kernel sizes in both F_2 populations. This demonstrated that as kernel size increased the weight of 100-kernels increased in direct proportion.

Figure 4 shows the frequency histograms for grain weight of the two F_2 populations. The class interval of 25-35 grams with a mean of 30 grams had the most plants in population-1, while the class interval of 15-25 grams with a mean of 20 grams had the most plants in population-2. Population-1 showed the highest grain weight (110 grams) compared to 90 grams in population-2. The distributions of grain weight versus kernel size (Figure 5) showed that the kernels of size 11/64 inch had the plants with the heaviest grain weight, and also the widest distribution for grain weight in both F_2 populations. Since kernel size 12/64 inch failed to have the heaviest grain weight it may be that grain weight can be increased along with increasing kernel size to a certain point (size of 11/64 inch in the present case) beyond which grain weight does not increase with further increased kernel size. This same situation prevailed in both F_2 populations. If the effect of height and maturity are ignored, it appears to be possible to select plants with both high yield and large kernel size.

In Figure 6 the frequency histograms of kernel number for both F_2

 28

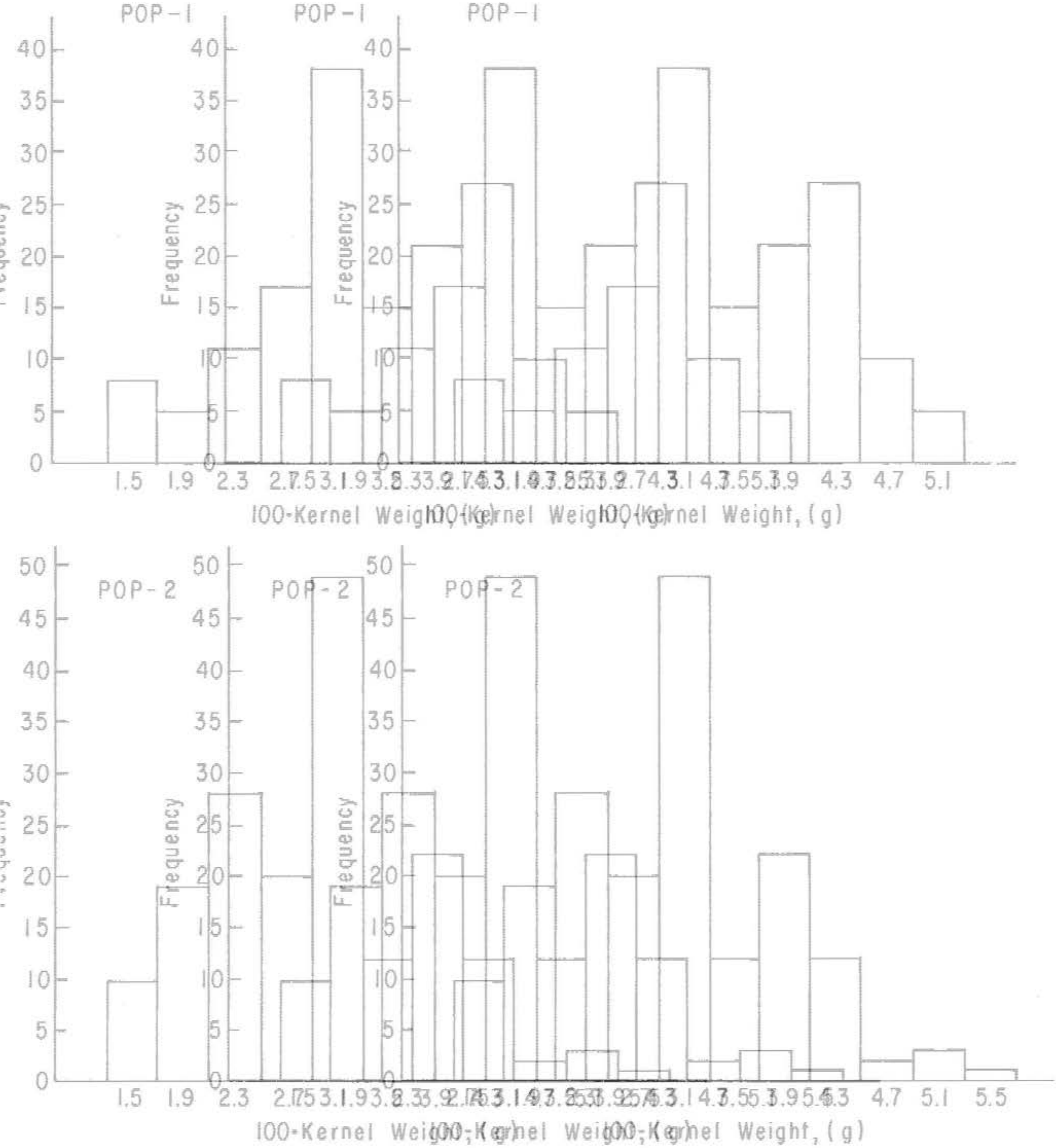

Figure 2. Frequency Distributions of 100-Kernel Weight

LEGEND: Numbers = Pop. 1; Letters = Pop. 2
1 = 1 obs, 2 = 2 obs, 3 = 3 obs, etc.
A = 1 obs, B = 2 obs, C = 3 obs, etc.

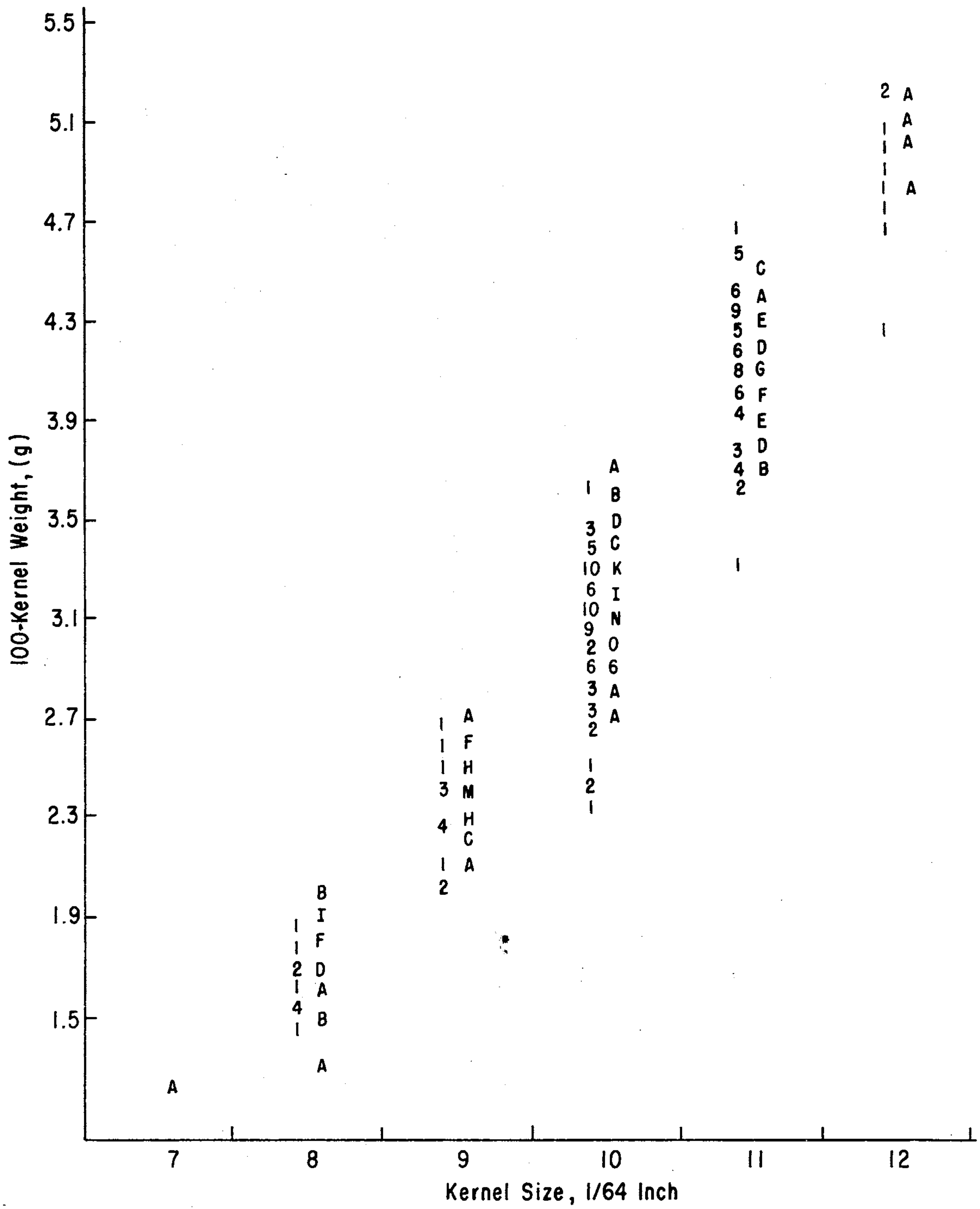

Figure 3. Distributions of 100-Kernel Weight vs. Kernel Size

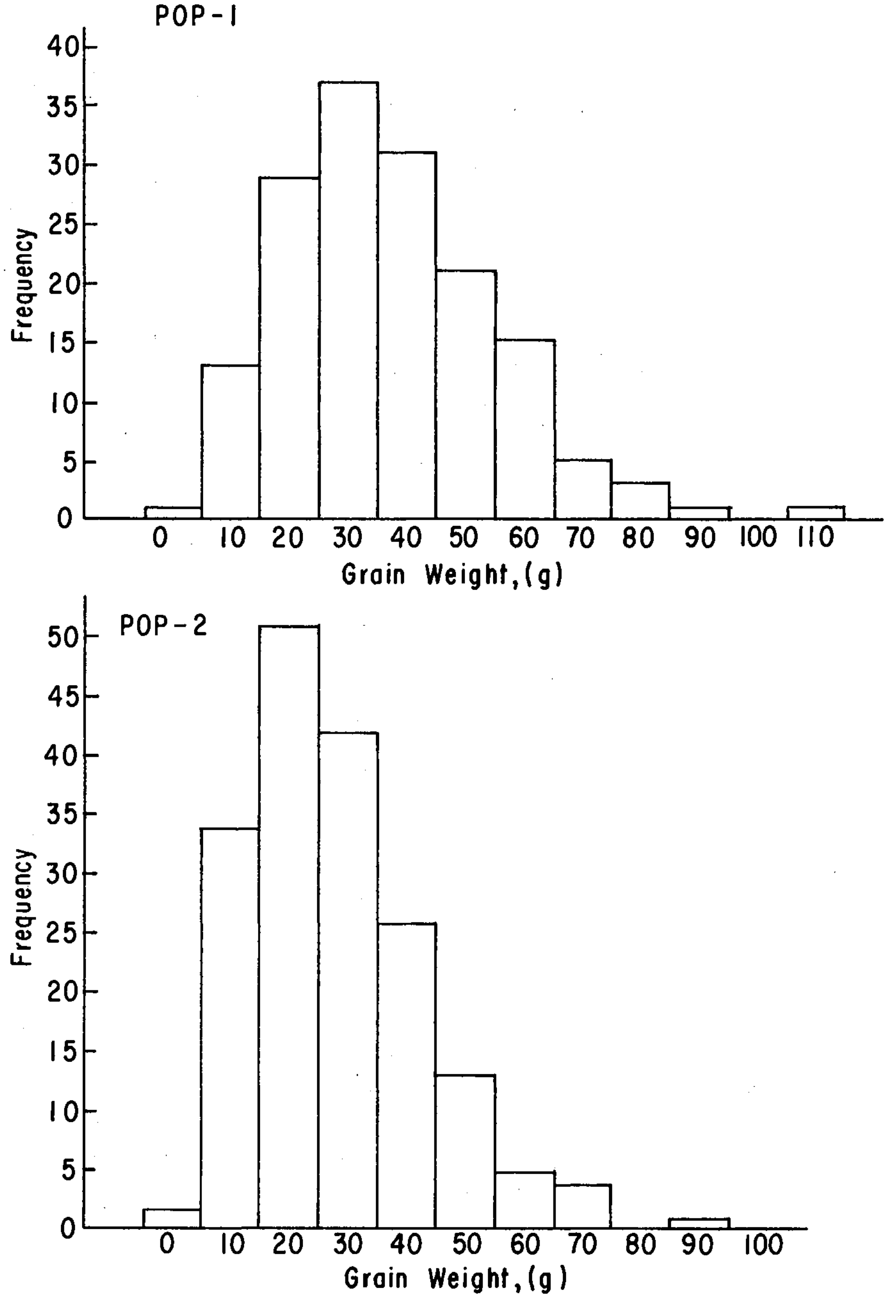

Figure 4. Frequency Distributions of Grain Weight

LEGEND: Numbers = Pop. 1, Letters = Pop. 2
1 = 1 obs, 2 = 2 obs, 3 = 3 obs, etc.
A = 1 obs, B = 2 obs, C = 3 obs, etc.

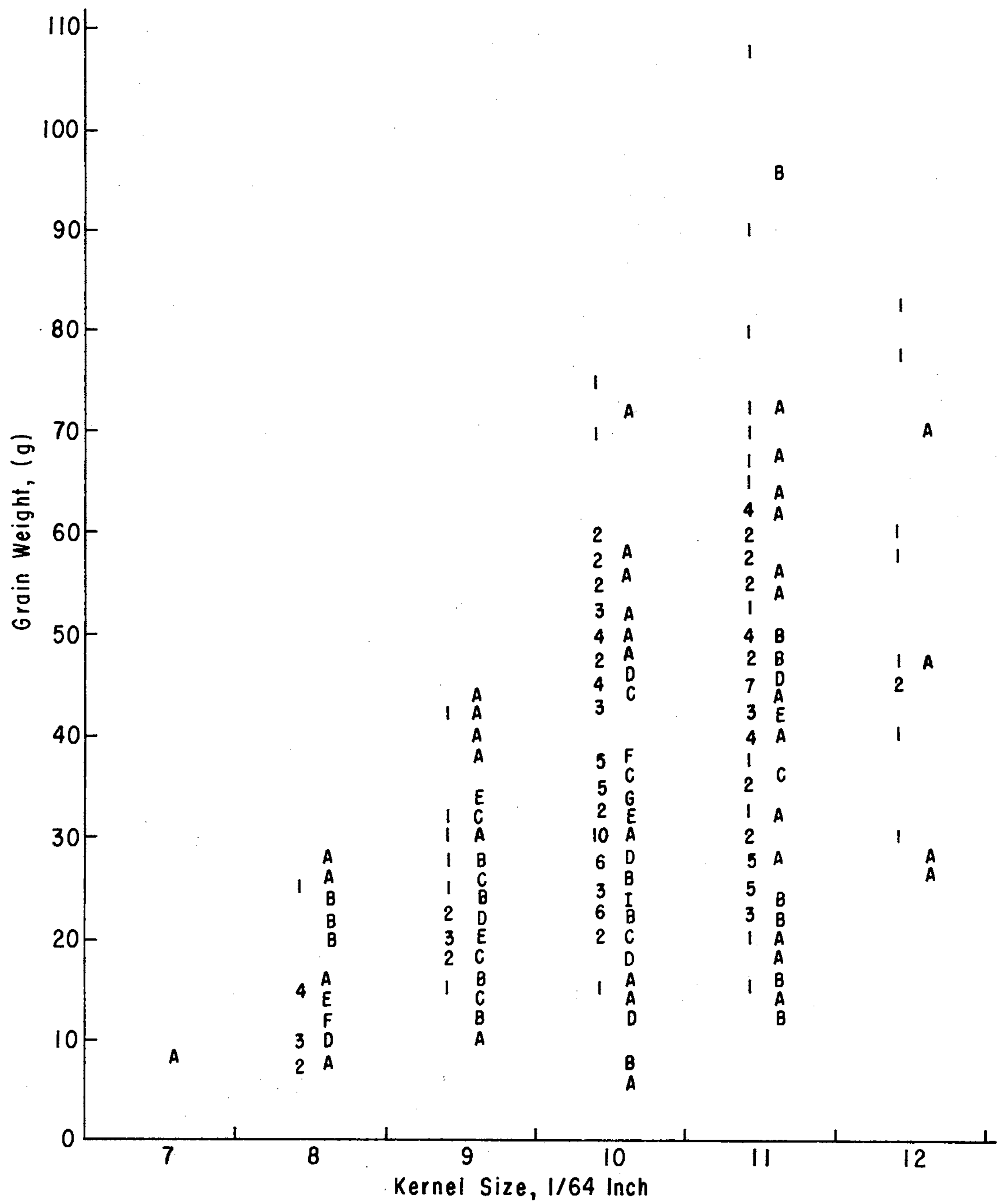

Figure 5. Distributions of Grain Weight vs. Kernel Size

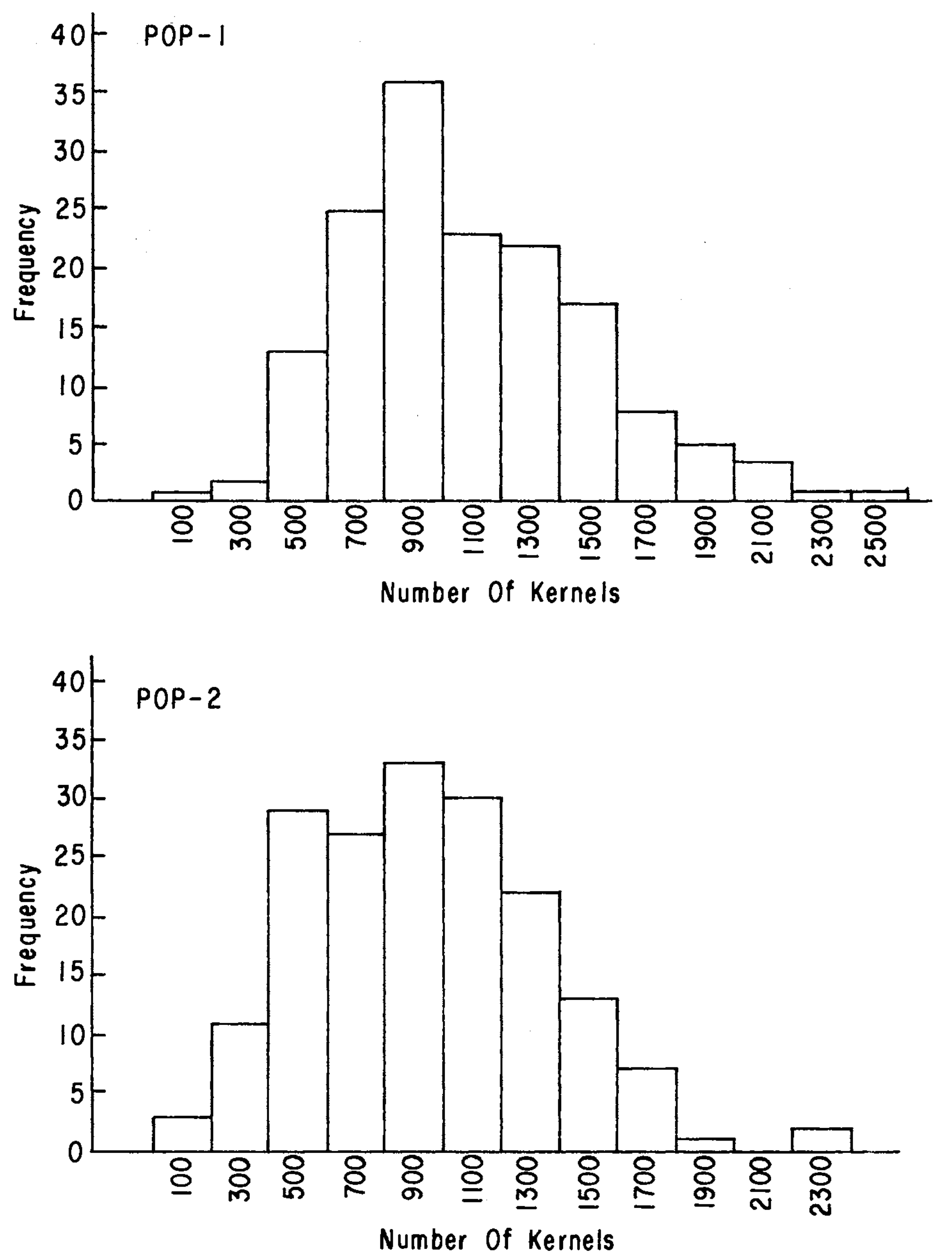

Figure 6. Frequency Distributions of Kernel Number

populations showed the class interval of 800-1000 grains with an average of 900 grains to be the largest class. The highest number of kernels was found in population-1. In Figure 7 kernel number per plant was plotted against kernel size. The wide distribution of plants for number of kernels per plant among the kernel size classes, again appeared to indicate that it would be possible to select plants with many grains (high grain weight) and with large kernels.

Figure 8 shows the frequency histograms of days-to-bloom. The major part of the plants in both F_2 populations showed an average of 55.5 days-to-bloom. In population-1 all plants flowered within the interval of 48 to 69 days after planting, while in population-2 all plants flowered in the interval of 45 to 69 days. Figure 9 gives the distributions of days-to-bloom versus kernel size. Days-to-bloom do not depend on kernel size since plants with kernel size of 10/64 inch contained the earliest plants and at the same time the latest ones.

The frequency histogram for height of population-1 (Figure 10) showed the plants of 48 to 52 inches in height formed the largest class. Height data were not available for population-2.

The distributions of grain weight versus 100-kernel weight (Figure 11) showed an almost identical distribution to that of grain weight versus kernel size for both populations. Plants with 100-kernel weight average of 4.3 grams contained the plants with the highest grain weight. This suggested the possibility of increased grain weight with increased 100-kernel weight.

Analysis of Variance

Variabilities were estimated using standard deviations. Means,

LEGEND: Numbers = Pop. 1, Letters = Pop. 2
1 = 1 obs, 2 = 2 obs, 3 = 3 obs, etc.
A = 1 obs, B = 2 obs, C = 3 obs, etc.

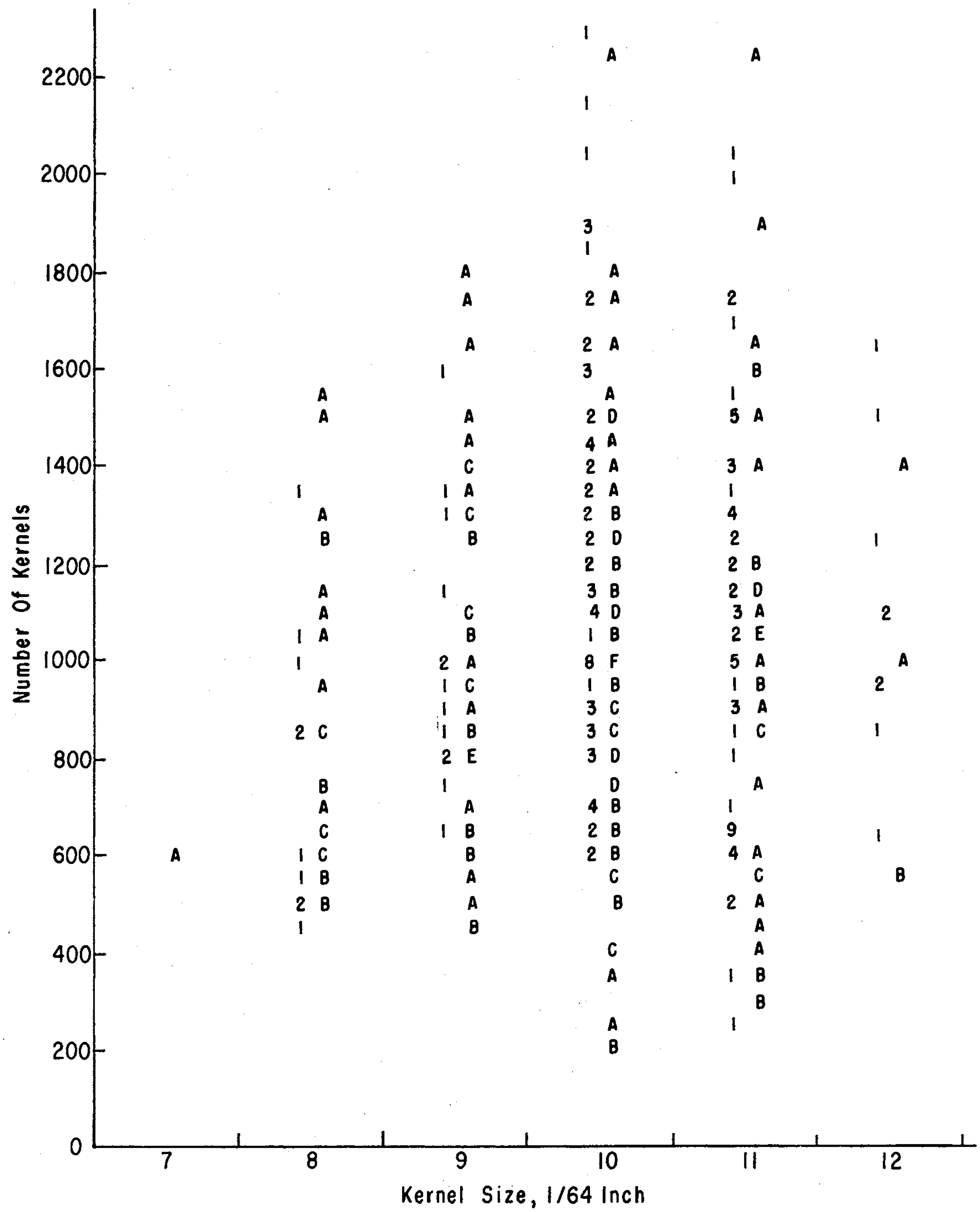

Figure 7. Distributions of Kernel Number vs. Kernel Size

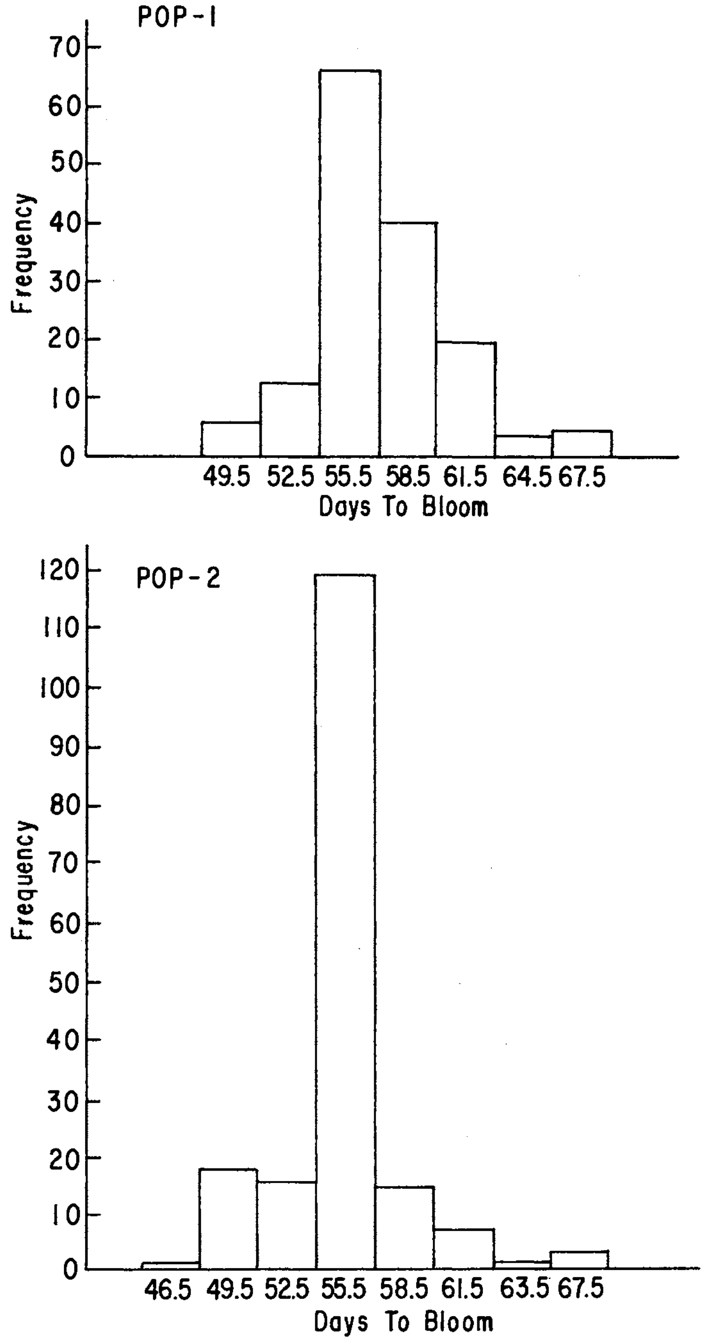

Figure 8. Frequency Distributions of Days-to-Bloom

LEGEND: Numbers = Pop. 1, Letters = Pop. 2
1 = 1 obs, 2 = 2 obs, 3 = 3 obs, etc.
A = 1 obs, B = 2 obs, C = 3 obs, etc.

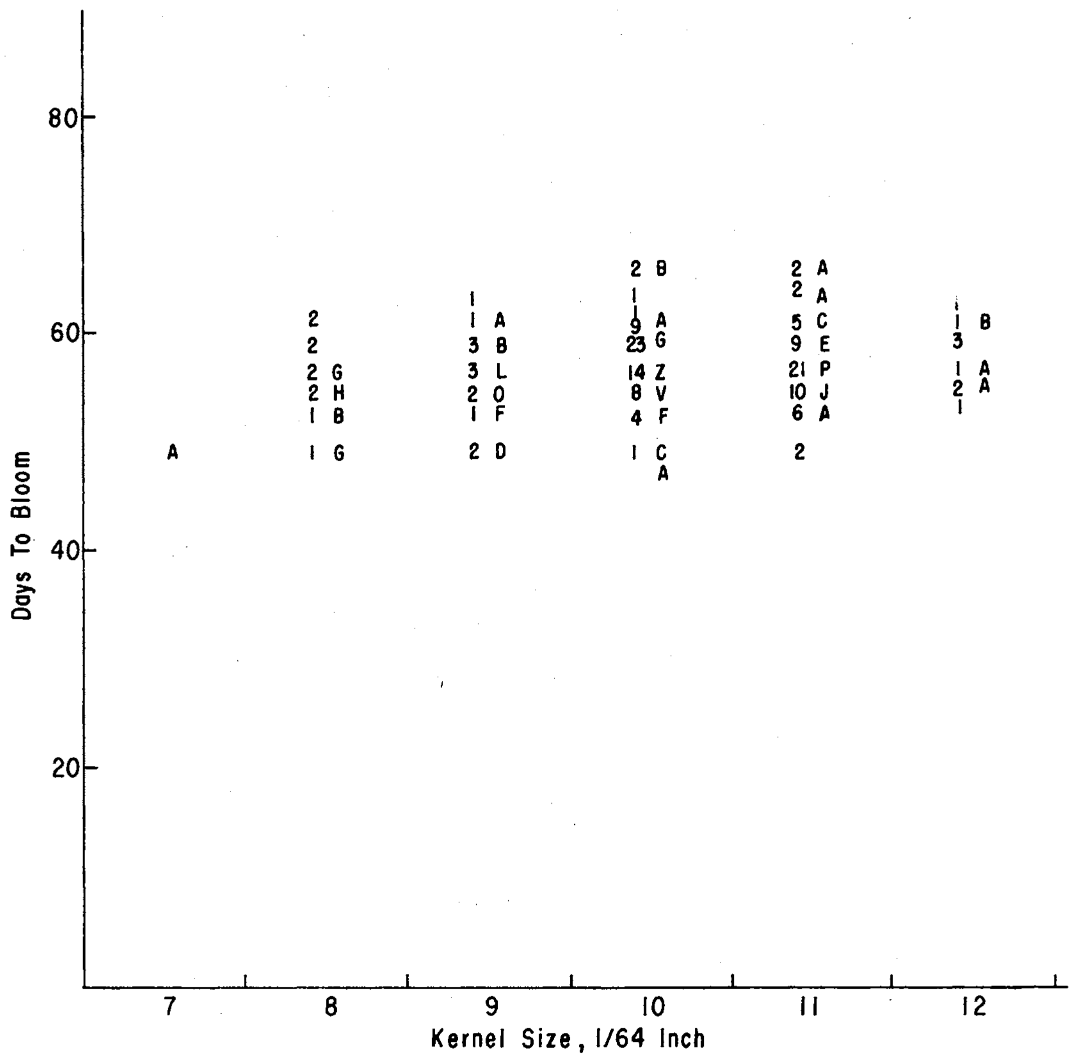

Figure 9. Distributions of Days-to-Bloom vs. Kernel Size

37

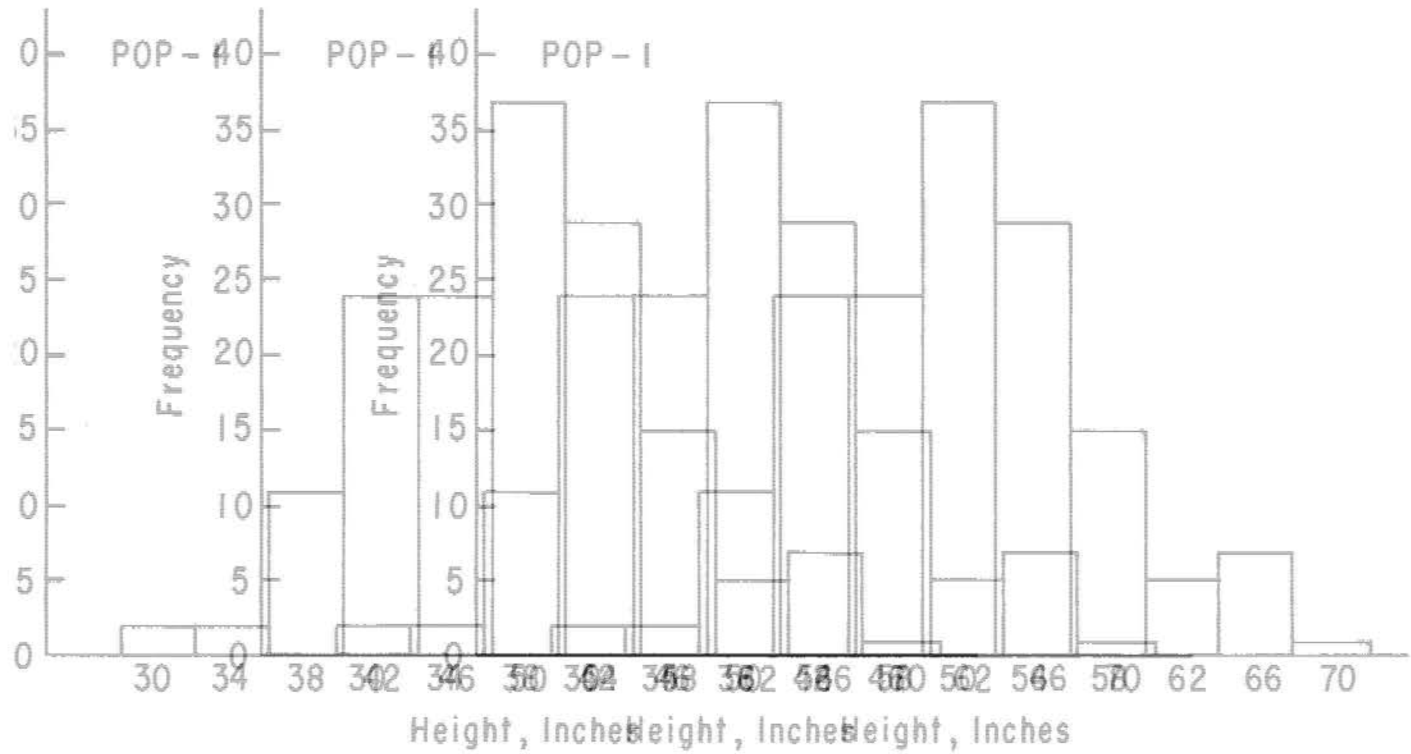

Figure 10. Frequency Distributions of Height

LEGEND: Numbers = Pop. 1, Letters = Pop. 2
1 = 1 obs, 2 = 2 obs, 3 = 3 obs, etc.
A = 1 obs, B = 2 obs, C = 3 obs, etc.

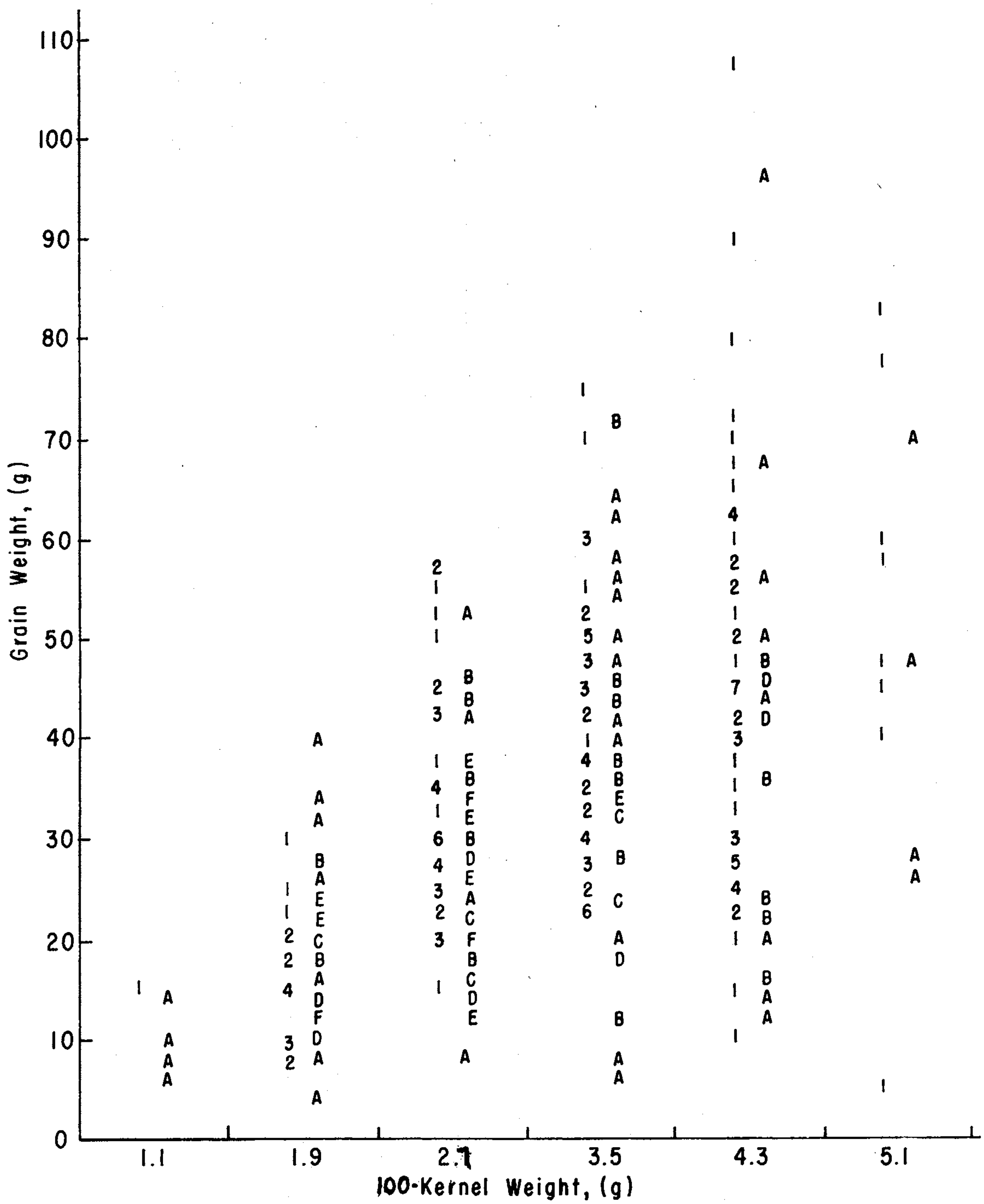

Figure 11. Distributions of Grain Weight vs. 100-Kernel Weight

ranges, and standard deviations were calculated for individual characters studied within each F_2 population and for the characters within each class of kernel size, separately.

The analyses of variability for individual characters of the two F_2 populations are given in Table II. The differences between means of kernel size of the two populations was 0.56 where the mean of population-1 was superior. The kernel size of 12/64 inch was the largest kernel size in both populations. The smallest kernel size occurred in population-2. The deviation from the mean was slightly larger in population-2. The data for 100-kernel weight showed the mean of population-1 to be larger than the mean of population-2 by 0.41 grams. A narrower range was obtained in population-1 than in population-2, and the highest value for 100-kernel weight occurred in population-2. The standard deviations showed practically no difference in the deviations from the means for both populations. Data for grain weight showed the mean of population-1 to be higher than the mean of population-2, and the highest grain weight was found in population-1. The range was larger in population-1 than in population-2. The standard deviations showed high deviations from the population mean for both populations with the highest deviation in population-1. Kernel number showed the highest mean in population-1. The range was wider in population-1 and the largest number of kernels per head for an individual plant was obtained in population-1. Population-1 showed also the largest deviation from the mean for kernel number. Days-to-bloom showed a difference of 2 days between means of the 2 populations. The ranges for days-to-bloom were 49-66 days for population-1 and 47-66 days for population-2. The earliest plants were observed in population-2. The deviations from the mean for days-to-bloom were low in both popula-

TABLE II

VARIANCE ANALYSIS OF INDIVIDUAL CHARACTERS IN TWO F_2 POPULATIONS

Characters	Pop. Number	df.	Mean	Range		Standard Deviation
				Min-Value	Max-Value	
Kernel Size 64th Inch	1	156	10.29	8.00	12.00	0.94
	2	176	9.73	7.00	12.00	1.04
100-Kernel Wt. Grams	1	156	3.40	1.40	5.22	0.87
	2	176	2.99	1.11	5.62	0.85
Grain Weight Grams	1	156	37.33	6.40	106.40	17.64
	2	176	28.28	5.75	94.30	15.08
Kernel Number	1	156	1090.24	202.05	2533.33	421.05
	2	176	942.99	174.24	2208.43	396.32
Days-to-Bloom	1	153	57.05	49.00	66.00	3.70
	2	174	55.01	47.00	66.00	3.19
Height Inches	1	156	48.87	29.00	68.00	7.75

tions but slightly larger in population-1. Data for height were obtained only for population-1 which showed a mean of 48.9 inches ranging from 29 to 68 inches and a deviation from the mean of 7.75.

Data for characters within each kernel size for the two F_2 populations are presented in Tables III, IV, V, VI, and VII. Table III shows the analysis of variability for characters within kernel size 8 of the two F_2 populations. Mean, range, and standard deviation for 100-kernel weight were all larger in population-2 than in population-1. The deviations from the means were small in both populations which suggested a distribution close to the mean for 100-kernel weight. The data for grain weight showed that population-2 had the larger mean, larger range of distribution and larger deviation from the mean compared to population-1. Mean values were 14.77 in population-2 and 11.96 in population-1. Deviations from the means were high in both populations. The highest mean in kernel number was obtained in population-2. High deviations from the mean in both populations made kernel number a highly variable character regardless of the population concerned. Days-to-bloom ranging from 49 to 61 days with an average of 56.10 in population-1 and from 49 to 56 days with an average of 52.95 days in population-2 suggested that it takes less time for plants with kernel size 8 to mature in population-2. Low deviations from the means were obtained in both populations. Data for height was obtained for population-1 and showed a range from 29 to 50 inches with a mean of 42 inches.

In the comparison of data for kernel size 8 with data for the whole population, 100-kernel weight, grain weight, and kernel number all showed a reversal of superiority between the populations. This might be explained on the basis that there were less plants with kernel size

TABLE III

VARIANCE ANALYSIS OF CHARACTERS WITHIN KERNEL SIZE 8 IN TWO F_2 POPULATIONS

Characters	Pop. Number	N	Mean	Range Min-Value	Range Max-Value	Standard Deviation
100-Kernel Wt. Grams	1	10	1.59	1.40	1.80	0.13
	2	25	1.74	1.23	2.00	0.18
Grain Weight Grams	1	10	11.96	6.40	23.60	5.13
	2	25	14.77	7.70	26.35	5.83
Kernel Number	1	10	748.40	426.66	1333.33	302.96
	2	25	845.54	452.94	1540.93	321.73
Days-to-Bloom	1	10	56.10	49.00	61.00	3.96
	2	24	52.95	49.00	56.00	2.84
Height Inches	1	10	42.00	29.00	50.00	6.45

8 in population-1 than in population-2 and that a biased sample was observed. The possibility is more likely that because the male parent of population-2 had the smallest kernels of all parents, plants with kernel size 8 in population-2 included plants with greater fittness than population-1. The fact that the population-2 plants averaged approximately three days earlier to bloom should not have been a contributing factor since growing conditions were favorable.

Table IV shows the data for the characters within kernel size 9. An increase in the means for 100-kernel weight was obtained in both populations compared to kernel size 8. The average 100-kernel weight was higher in population-2 than in population-1. The deviation from the mean was higher in population-1. For grain weight little difference between the means of the two populations was obtained, but the range was larger in population-2. The standard deviations from the means were relatively high for both populations. Data for kernel number showed only a slight difference in the means of the 2 populations, but there was a larger range in population-2 as well as a higher deviation from the mean. The mean of days-to-bloom showed that population-1 required approximately 1.7 more days to reach flowering than did population-2. A higher deviation was obtained in population-1, but both deviations were low. Data for height were obtained for kernel size 9 of population-1. The mean was 50.15 which was higher than in kernel size 8. Again there was a reversal of superiority of magnitude for 100-kernel weight, grain weight, and kernel number for kernel size 9 compared to the whole population.

No difference was apparent between means of 100-kernel weight for kernel size 10 (Table V) of the two F_2 populations. An increase in

TABLE IV

VARIANCE ANALYSIS OF CHARACTERS WITHIN KERNEL SIZE 9 IN TWO F_2 POPULATIONS

Characters	Pop. Number	N	Mean	Range Min-Value	Range Max-Value	Standard Deviation
100-Kernel Wt. Grams	1	13	2.28	1.98	2.60	0.21
	2	40	2.38	2.10	2.63	0.12
Grain Weight Grams	1	13	22.76	14.10	40.30	7.44
	2	40	23.85	10.00	44.00	8.89
Kernel Number	1	13	989.37	643.83	1562.01	272.28
	2	40	999.95	413.65	1752.98	359.20
Days-to-Bloom	1	13	55.92	49.00	63.00	4.31
	2	40	54.22	49.00	61.00	2.63
Height Inches	1	13	50.15	37.00	62.00	8.05

TABLE V

VARIANCE ANALYSIS OF CHARACTERS WITHIN KERNEL SIZE 10 IN TWO F_2 POPULATIONS

Characters	Pop. Number	N	Mean	Range Min-Value	Range Max-Value	Standard Deviation
100-Kernel Wt. Grams	1	64	3.04	2.30	3.61	0.27
	2	68	3.11	2.68	3.62	0.20
Grain Weight Grams	1	64	36.45	13.40	73.60	13.10
	2	68	29.50	5.75	70.45	13.01
Kernel Number	1	64	1196.25	553.71	2264.61	414.10
	2	68	948.42	174.24	2201.56	409.96
Days-to-Bloom	1	63	57.71	49.00	66.00	3.30
	2	68	55.23	47.00	66.00	3.14
Height Inches	1	64	47.90	36.00	65.00	6.73

deviations from the means was obtained for 100-kernel weight in both populations compared to their values in kernel size 9. The average grain weight was superior in population-1 over population-2 which was the reverse of what was obtained in kernel sizes 8 and 9. The deviations from the means of grain weight were high but similar. Unlike in kernel sizes 8 and 9 an increase in kernel number was obtained in population-1. Deviations from the means were also high in both populations. Again days-to-bloom for kernel size 10 was higher in population-1 than in population-2. Low deviations were obtained for days-to-bloom in both populations. A decrease in height was obtained compared to kernel size 9, but an increase compared to kernel size 8. Since grain weight and kernel number were greater in population-1 of kernel size 10, it appeared that the plants in population-1 (where both parents had large kernels) were able to express their genotypes sufficiently to exceed population-2 and compare with the average of all kernel sizes.

Table VI presents the data in kernel size 11. No noticeable difference was obtained in the means for 100-kernel weight of the two populations, but the larger value of 100-kernel weight was obtained in population-1. Though low, an increase in deviations was observed in both populations compared to the values in kernel sizes 8, 9, and 10. Grain weight showed a higher mean in population-1 than in population-2, and the highest value of grain weight was obtained in population-1. Deviations from the mean increased for both populations compared to their values in the smaller kernel sizes. As in kernel size 10 the average kernel number was higher in population-1 than in population-2 and the largest number of kernels per head was obtained in population-1. Deviations increased in both populations compared to their values in

TABLE VI

VARIANCE ANALYSIS OF CHARACTERS WITHIN KERNEL SIZE 11 IN TWO F_2 POPULATIONS

Characters	Pop. Number	N	Mean	Range Min-Value	Range Max-Value	Standard Deviation
100-Kernel Wt. Grams	1	60	4.11	3.30	4.62	0.28
	2	38	4.08	3.61	5.62	0.33
Grain Weight Grams	1	60	43.31	8.85	106.40	18.72
	2	38	38.82	10.90	94.30	18.28
Kernel Number	1	60	1056.62	202.05	2533.33	452.76
	2	38	957.19	284.67	2208.43	455.59
Days-to-Bloom	1	58	56.88	49.00	66.00	3.84
	2	37	56.62	52.00	66.00	2.94
Height Inches	1	60	50.45	30.00	68.00	8.56

smaller kernel sizes. An equal number of days-to-bloom was obtained for both populations, but deviation from the mean was larger in population-1 than in population-2. An increase in height was observed for population-1 compared to the smaller kernel sizes.

Table VII shows the variabilities in kernel size 12. An increase was obtained in 100-kernel weight compared to smaller kernel sizes. No difference between averages of 100-kernel weight of the two populations was evident but the higher 100-kernel weight was observed in population-1. The deviations from the mean increased in population-1 and decreased in population-2 compared to their respective values in kernel size 11. Grain weight was higher in population-1 than in population-2, and the highest grain weight was found in population-1. An increase in deviation from the mean was obtained in population-2, but a decrease in population-1 compared to kernel size 11. The average kernel number was larger in population-1 than in population-2. Also the largest number of kernels per head was obtained in population-1. The deviations were high in both populations but higher in population-2 than in population-1. An increase in number of days-to-bloom was observed in both populations compared to kernel size 11. The range of days-to-bloom was 52-62 days in population-1 and 54-61 days in population-2 with no plants as late as those in kernel sizes 10 and 11. Deviations from the means were low in both populations. Only a little increase was observed in height of kernel size 12 compared to kernel size 11.

The analyses of means, ranges and deviations showed an increase in the means for 100-kernel weight of approximately one gram for each kernel size class. Likewise there was an increase in grain weight per plant of approximately 10 grams for each kernel size class. Number of

TABLE VII

VARIANCE ANALYSIS OF CHARACTERS WITHIN KERNEL SIZE 12 IN TWO F_2 POPULATIONS

Characters	Pop. Number	N	Mean	Range Min-Value	Range Max-Value	Standard Deviation
100-Kernel Wt. Grams	1	9	4.83	4.22	5.22	0.31
	2	4	4.95	4.75	5.11	0.16
Grain Weight Grams	1	9	52.82	29.55	81.40	16.99
	2	4	41.90	24.60	69.00	20.67
Kernel Number	1	9	1086.03	640.99	1631.26	311.77
	2	4	842.45	517.89	1366.33	404.81
Days-to-Bloom	1	9	57.33	52.00	62.00	3.46
	2	4	58.00	54.00	61.00	3.56
Height Inches	1	9	50.88	43.00	59.00	5.46

kernels per plant reached its maximum in population-2 in kernel size 9, and in population-1 in kernel size 10. Beyond these limits the increase in grain weight was obtained through an increase in kernel size rather than kernel number. The mean for days-to-bloom increased approximately one day for each kernel size class in population-2, but it remained relatively the same throughout population-1. However, the ranges of days-to-bloom for both populations were wide in the kernel size classes 10 and 11. The means for plant height were relatively constant except that kernel size 8 was shorter. Kernel sizes 10 and 11 had ranges which involved the tallest plants. Kernel size 12 did not include plants as late or tall as did sizes 10 and 11.

The 100-kernel weight and grain weight increased progressively as kernel size increased. Kernel number did not increase beyond kernel size 9 for population-2 and beyond kernel size 10 for population-1. Therefore, an increase in grain yield from a population derived from large kernelled parents can be obtained only by maintaining the large kernels.

Correlation Coefficients

Simple correlation coefficients were calculated among all characters studied for both F_2 populations and among the characters within each class of kernel size separately. The results of these investigations are presented on Tables VIII, IX, X, XI, XII, and XIII.

Table VIII shows correlation coefficients among agronomic characters for the two F_2 populations. The correlation coefficient between kernel size and grain weight of .52 was highly significant in both F_2 populations. This suggested that large kernel size was associated with

TABLE VIII

CORRELATION COEFFICIENTS AMONG KERNEL SIZE AND VARIABLES IN TWO F_2 POPULATIONS

	Pop. Number	Kernel Size	100-Kernel Weight	Grain Weight	Kernel Number	Days to Bloom
100-Kernel Wt.	1	0.95**				
	2	0.96**				
Grain Weight	1	0.52**	0.52**			
	2	0.52**	0.52**			
Kernel Number	1	0.1	0.06	0.86**		
	2	0.05	0.02	0.84**		
Days-to-Bloom	1	0.03	-0.02	0.20*	0.25**	
	2	0.40**	0.44**	0.21	0.01	
Height	1	0.22	0.19*	0.36**	0.32**	0.21**

** Significant at 1% level
* Significant at 5% level

high grain weight, at least, in this material, and that it should be possible to select plants combining both characteristics. A positive and very high correlation coefficient was obtained between kernel size and 100-kernel weight (r = .95 in population-1 and r = .96 in population-2). This suggested that 100-kernel weight can be substituted for kernel size as it already has been by a number of workers. Kernel size was also significantly and positively correlated with days-to-bloom in population-2 (r = .40) but not in population-1. The correlation did not seem strong enough to preclude the selection of medium maturing plants with large kernels. Low correlation coefficients were calculated between kernel size and kernel number in both F_2 populations (r = .1 in population-1 and r = .05 in population-2), so that it may be possible to select plants with many large kernels.

Positive and highly significant correlation coefficients were obtained between grain weight and 100-kernel weight and between grain weight and kernel number in both F_2 populations. These high correlations might be expected since 100-kernel weight and kernel size are so closely related, and since grain weight and kernel size are closely related. Also a positive and significant correlation coefficient (r = .36) was obtained between grain weight and height in population-1. Although significant, the correlation was lower than some of the other coefficients and it does not establish that only tall plants could have high yield.

The correlation coefficient between 100-kernel weight and height was low but significant in population-1. No correlation was indicated between 100-kernel weight and days-to-bloom in population-1 but a positive, significant, correlation (r = .43) was obtained in population-2 indicating a tendency for late plants to have larger kernels. Height was positively and significantly correlated with days-to-bloom (r = .21) and with kernel number (r = .32) in population-1. Although significant, again these correlations were fairly low. Days-to-bloom was positively and significantly correlated with kernel number in population-1 (r = .25) but not in population-2. Again the low correlation did not establish that only late plants could have high yield.

Correlation coefficients between kernel size and grain weight (r = .52 in each of the two F_2 populations) compared to correlation coefficients between kernel number and grain weight (r = .86 in F_2 population-1 and r = .84 in F_2 population-2) suggest that grain weight or grain yield can be increased either by increasing kernel size or by increasing kernel number. These two characters (large kernel size and large kernel number) can be combined in the same plant as the very low and nonsignificant correlation between them demonstrates. According to the coefficients, kernel number and kernel size seem to be the best characters for increasing grain yield.

Correlation coefficients among characters within kernel size 8 (Table IX) showed positive and highly significant correlation between grain weight and kernel number (r = .97) in each of the two F_2 populations and between height and days-to-bloom (r = .81 in population-1). The remaining characters having very low or negative correlation coefficients.

Within kernel size 9 (Table X) correlations were positive and highly significant between grain weight and kernel number (r = .97 and r = .99) in populations-1 and -2, respectively. The same table showed positive and highly significant correlations between grain weight and

TABLE IX

CORRELATION COEFFICIENTS AMONG CHARACTERS WITHIN KERNEL SIZE 8 IN TWO F_2 POPULATIONS

	Pop. Number	100-Kernel Weight	Grain Weight	Kernel Number	Days to Bloom
Grain Weight	1	0.21			
	2	0.24			
Kernel Number	1	-0.01	0.97**		
	2	-0.01	0.97**		
Days-to-Bloom	1	-0.07	0.18	0.18	
	2	-0.08	0.04	0.07	
Height	1	-0.01	0.36	0.37	0.81**

** Significant at 1% level
* Significant at 5% level

TABLE X

CORRELATION COEFFICIENTS AMONG CHARACTERS WITHIN KERNEL SIZE 9 IN TWO F_2 POPULATIONS

	Pop. Number	100-Kernel Weight	Grain Weight	Kernel Number	Days to Bloom
Grain Weight	1	0.56*			
	2	0.23			
Kernel Number	1	0.33	0.97**		
	2	0.10	0.99**		
Days-to-Bloom	1	-0.35	-0.08	-0.02	
	2	0.42**	0.27	0.22	
Height	1	-0.07	-0.10	-0.07	0.15

** Significant at 1% level
 * Significant at 5% level

100-kernel weight in population-1 and between days-to-bloom and 100-kernel weight in population-2 (r = .42).

Correlation coefficients between grain weight and kernel number were positive and highly significant in both populations within kernel size 10 (Table XI). Also positive and significant correlations were obtained between height and kernel number in population-1 (r = .35) and between 100-kernel weight and days-to-bloom in population-2 (r = .34).

Grain weight and kernel number showed a positive and highly significant correlation coefficient in both F_2 populations within kernel size 11 (Table XII). In population-1 positive and significant correlations were obtained between grain weight and height (r = .36), height and days-to-bloom (r = .37), and height and kernel number (r = .34).

Within kernel size 12 (Table XIII) positive and highly significant correlations were obtained only between grain weight and kernel number (r = .98 in population-1 and r = .99 in population-2).

The results obtained showed close relationships between kernel size and 100-kernel weight, kernel size and grain weight, grain weight and 100-kernel weight, and between grain weight and kernel number. There was a lack of correlation between kernel size and kernel number and between kernel number and 100-kernel weight. The relationships are shown below:

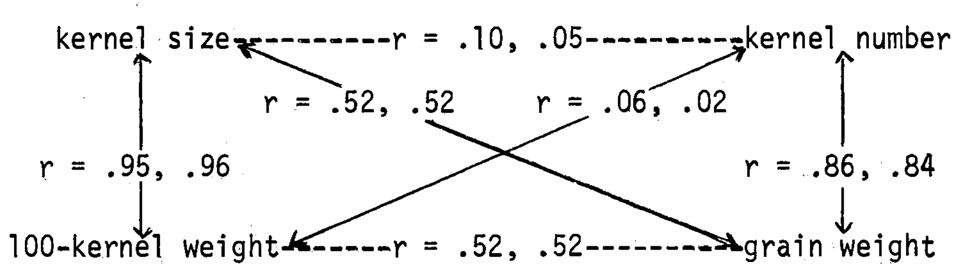

TABLE XI

CORRELATION COEFFICIENTS AMONG CHARACTERS WITHIN KERNEL SIZE 10 IN TWO F_2 POPULATIONS

	Pop. Number	100-Kernel Weight	Grain Weight	Kernel Number	Days to Bloom
Grain Weight	1	0.21			
	2	0.11			
Kernel Number	1	-0.01	0.97**		
	2	-0.02	0.99**		
Days-to-Bloom	1	-0.12	0.24	0.26*	
	2	0.34**	0.02	-0.03	
Height	1	-0.25	0.21*	0.35**	0.02

** Significant at 1% level
* Significant at 5% level

TABLE XII

CORRELATION COEFFICIENTS AMONG CHARACTERS WITHIN KERNEL SIZE 11 IN TWO F_2 POPULATIONS

	Pop. Number	100-Kernel Weight	Grain Weight	Kernel Number	Days to Bloom
Grain Weight	1	0.05			
	2	0.01			
Kernel Number	1	-0.11	0.99**		
	2	-0.15	0.98**		
Days-to-Bloom	1	-0.22	0.19	0.22	
	2	0.12	-0.27	-0.27	
Height	1	0.04	0.36**	0.34**	0.37**

** Significant at 1% level
 * Significant at 5% level

TABLE XIII

CORRELATION COEFFICIENTS AMONG CHARACTERS WITHIN KERNEL SIZE 12 IN TWO F_2 POPULATIONS

	Pop. Number	100-Kernel Weight	Grain Weight	Kernel Number	Days to Bloom
Grain Weight	1	0.59			
	2	0.36			
Kernel Number	1	0.44	0.98**		
	2	0.32	0.99**		
Days-to-Bloom	1	0.55	0.36	0.27	
	2	-0.04	0.86	0.88	
Height	1	0.18	0.24	0.24	-0.23

** Significant at 1% level
 * Significant at 5% level

The correlations seemed to indicate that grain weight could be increased by selection for kernel number or for kernel size. It appeared that kernel size was independent of kernel number, and that it should be possible to select plants with both large kernel number and large kernel size.

CHAPTER V

SUMMARY AND CONCLUSIONS

A study of the relationships between kernel size and other important agronomic characters was conducted at the Perkins Agronomy Research Station and in the Sorghum Breeding Laboratory at Oklahoma State University. The experimental material was composed of two F_2 populations derived from different crosses. The experimental plot was made up of four rows approximately 25 feet long containing 157 plants of F_2 population-1 and 178 plants of F_2 population-2 for which data were obtained.

The purpose of this study was to investigate the relationships between kernel size and agronomic characters and to find out whether large kernel size could be increased while maintaining or increasing yield. Five classes of kernel size were obtained for each population. For each character involved means, ranges, and standard deviations were computed. Histograms of the frequency distributions were constructed for each character, and simple correlation coefficients among characters were calculated.

The frequency distributions of kernel size and 100-kernel weight showed that plants with kernels of size 10, and plants having 100-kernel weights ranging between 2.9 and 3.3 grams were most frequent in both populations. Plants with grain weights of 25 - 35 grams were the most frequent in population-1 while plants with 15 - 25 grams were most frequent in population-2. Plants having kernel numbers ranging from

800 to 1000 kernels per head were the most frequent in both populations. Days-to-bloom averaged 55.5 days for both populations, while the average height of plants in population-1 was 50 inches. The difference in average grain weight per head suggested a superiority in yield of population-1 over population-2. The frequency distribution of 100-kernel weight versus kernel size showed an increase in 100-kernel weight parallel to an increase of kernel size. In the distribution of grain weight versus kernel size, the heaviest grain weights were found in kernel size 11. This suggested that it was possible to select plants with heavy grain weight (yield) and large kernels. In the distribution of kernel number per head versus kernel size, kernel number per head increased with increasing kernel size up to 10/64 inch. The frequency distribution of kernel size versus days-to-bloom showed no relationship between the characters in either population.

The means for 100-kernel weight and grain weight increased progressively as kernel size increased. Kernel number per head did not increase beyond kernel size 9 for population-2 nor beyond kernel size 10 for population-1. Therefore, an increase in grain yield per plant from a population derived from large kernelled parents can be obtained only by maintaining large kernel size. The means for days-to-bloom increased approximately one day for each kernel size class in population-2, but it remained relatively the same throughout the kernel size classes of population-1. Since there was an increase in mean grain weight as kernel size increased in population-1 while days-to-bloom and plant height remained relatively constant, then the usual pattern of increased yield for late and tall plants did not hold in population-1. It should be possible to select high yielding plants with large kernels independent of height and maturity.

The correlation studies revealed close association between kernel size and 100-kernel weight, between kernel size and grain weight, between grain weight and 100-kernel weight, and between grain weight and kernel number. There was a lack of association between kernel size and kernel number and between kernel number and 100-kernel weight.

It was concluded that grain weight could be increased by selection for either kernel number or kernel size. Since kernel size seemed to be independent from kernel number, it should be possible also to select plants with both large kernels and many kernels.

Although some significant correlations were obtained between both grain weight and kernel size with days-to-bloom and height, the coefficients were relatively small and did not appear to preclude the selection of high yielding plants with large kernels in the medium range for height and maturity.

LITERATURE CITED

1. Adams, M. W. 1967. Basis of yield component compensation in crop plants with special reference to the field bean, Phaseolus vulgaris. Crop Sci. 7: 505-510.

2. Anderson, V. L. and O. Kempthorne. 1954. A model for the study of quantitative inheritance. Genetics 39: 883-898.

3. Atkins, R. E., V. H. Reich, G. M. Beil, and J. S. Kirby. 1968. Interrelationships among dry weight of panicles, threshing percentage and grain yield in sorghum. Agron. J. 60: 219-222.

4. Aycock, H. S. and L. F. Bauman. 1971. Effect of selection for relative kernel weight in heterozygous opaque-2 and floury-2 maize populations. Agron. Abstr. p. 3.

5. Blum, A. 1970. Nature of heterosis in grain production by the sorghum panicle. Crop Sci. 10: 28-31.

6. Bremner, P. M., R. N. Eckersall, and R. K. Scott. 1963. The relative importance of embryo size and endosperm size in causing the effects associated with size in wheat. J. Agr. Sci. 61: 139-145.

7. Cagampang, I. C. 1969. A study of plant type and combining ability in Sorghum vulgare Pers. in relation to soil fertility and plant population. (Diss. Abstr. 29: 2713-B).

8. Chakravorty, S. C. 1967. Chemical study of sorghum as a staple food in India. II. Protein content in relation to Jowar grains. Ind. Agr. 11: 113-116.

9. Chapman, S. R. and F. H. McNeal. 1971. Gene action for yield components and plant height in a spring wheat cross. Crop Sci. 11: 384-386.

10. Chiang, M. S. and J. D. Smith. 1967. Diallel analysis of the inheritance of quantitative characters in grain sorghum. Can. J. Gen. Cytol. 9: 44-51.

11. Dalton, L. G. 1967. A positive regression of yield on maturity in sorghum. Crop Sci. 7: 271.

12. Douglas, R. D. and K. H. Lu. 1959. A correlation and path-coefficient analysis of components of crested wheat grass seed production. Agron. J. 51: 515-518.

13. Fanous, M. A., D. E. Weibel, and R. D. Morrison. 1971. Quantitative inheritance of some head and seed characteristics in sorghum Sorghum bicolor (L.) Moench. Crop Sci. 11: 787-789.

14. Garg, D. K., M. L. H. Koul, and S. P. Singh. 1973. Correlations among seed characteristics of 41 varieties of pearl millet. Ind. J. Agr. Sci. 43: 21-24.

15. Hayes, H. K., F. R. Immer, and D. C. Smith. 1955. Methods of plant breeding. McGraw-Hill. New York.

16. Holt, E. C. 1962. Growth behavior and management of small grains for forage-seed size effects on performance of dryland grasses. Agron. J. 54: 277-278.

17. Hussain, M. K. Muhammad Amin Khan. 1973. Correlation studies in sorghum-sudangrass hybrid forage. Sabrao Sorghum Newsletter. 5: 51-53.

18. Hsu, P. and P. D. Walton. 1971. Relationships between yield and its components and structures above the flag leaf node in spring wheat. Crop Sci. 11: 190-193.

19. Ireland, J. C. 1938. Sorghum characters grouped by multiple correlations. J. Agr. Res. 56: 707-710.

20. Jellum, M. D. and J. B. Powell. 1971. Fatty acid composition of oil from pearl millet seed. Agron. J. 63: 29-33.

21. Jones, M. D. and J. B. Sieglinger. 1952. Effect of the waxy gene on grain yields of sorghum. Okla. Agri. Exp. Sta. Tech. Bull. No. T-44.

22. Khole, A. K. 1951. Study of correlations of East Kandesh Jowars Andropogon sorghum. Poona Agr. Coll. Mag. 42: 10-14

23. Kirby, J. S. and R. E. Atkins. 1968. Heterotic response for vegetative and mature plant characters in grain sorghum Sorghum bicolor (L.) Moench. Crop Sci. 8: 335-339.

24. Liang, G. H. 1967. Diallel analysis of agronomic characters in grain sorghum Sorghum vulgare Pers. Can. J. Genet. Cytol. 9: 269-276.

25. _____, C. B. Overley, and A. J. Casady. 1969. Interrelations among agronomic characters in grain sorghum Sorghum bicolor (L.) Moench. Crop Sci. 9: 299-302.

26. Liang, G. H., C. R. Reddy, and A. D. Dayton. 1972. Heterosis, inbreeding depression, and heritability estimates in a systematic series of grain sorghum genotypes. Crop Sci. 12: 409-411.

27. _____, and T. L. Walter. 1968. Heritability estimates and gene effects for agronomic traits in grain sorghum, Sorghum vulgare, Pers. Crop Sci. 8: 77-81.

28. Majisu, B. N. 1971. Effects of autoploidy on grain sorghum. East Afri. Agr. Forest. J. 36: 235-243.

29. Malm, N. R. 1968. Exotic germplasm use in grain sorghum improvement. Crop Sci. 8: 295-298.

30. Martin, J. H. 1929. Plant characters and yield in grain sorghum. J. Amer. Soc. Agron. 20: 1172-1182.

31. _____. 1936. Sorghum improvement. In Yearbook. Agr. (US Dept. Agri.) US Government Printing Office, Washington, D.C. p. 523-560.

32. Moolani, M. K. 1968. Correlation of some plant characters with yield in T-55 bajara. Pennisetum typhoides Pers. Ind. J. Sci. Ind. 2: 19-26.

33. Moore, C. A. and D. G. Nelson. 1970. The future of grain sorghum. In Wall, J. S. and W. M. Ross. Sorghum production and utilization. The AVI Publishing Co., Inc. Westport, Conn.

34. Phadnis, B. A., M. A. Tayyab, and B. C. Ghawghawe. 1967. Evaluating better foundation seed parent for use in sorghum hybrid production programme. Nagpur Agri. Coll. Mag. 68: 40.

35. Quinby, J. R. 1963. Manifestation of hybrid vigor in sorghum. Crop Sci. 3: 288-291.

36. _____. 1967. The maturity genes for sorghum. Advance. Agron. 19: 267-305.

37. _____. 1973. The genetic control of flowering and growth in sorghum. Advance Agron. 25: 125-160.

38. _____. 1968. Opportunities for sorghum improvement. Amer. Seed Trade Assn. 23: 170-176.

39. Rao, N. G. P., G. Harinayana, V. Arunackalam, D. P. Tripath and K. Bala Kotaiak. 1973. Genetic analysis of some exotic x Indian crosses in sorghum. VI Character association under selection. Ind. J. Genet. Plt. Breed. 33: 1-6.

40. Reddy, G. R. and C. H. Liang. 1971. Genetic variability of yield in F_2 populations of grain sorghum Sorghum bicolor (L.) Moench. Canad. J. Genet. Cytol. 13: 101-104.

41. Sage, G. C. M. 1973. The expression of heterosis for yield in restored F_1 hybrid wheats and its interactions with seed rate and seed size. J. Agr. Sci. Camb. 81: 125-129.

42. Schaeffer, J. S. and J. H. Kim. 1971. Selection for female fertility and seed size in male-sterile intermediate wheat grass, Agropyron intermedium. Crop Sci. 11: 588-589.

43. Schaffer, R. E., D. L. Oswalt, and R. C. Pickett. 1972. Genotype by environment interaction effects for grain yield, protein, lysine, oil and seed weight of Sorghum bicolor (L.) Moench. Agron. Abst. p. 19.

44. Vichitr, Benjasil. 1968. Effects of mass selection for quantitative traits in sorghum. (Diss. Abstr. 29: 12335).

45. Voigt, R. L., C. O. Gardner, and O. J. Webster. 1966. Inheritance of seed size in sorghum Sorghum vulgare Pers. Crop Sci. 6: 582-586.

46. Wright, L. N. and R. L. Major. 1971. Influence of seed weight of blue Panicgrass Panicum antidotale (Retz), selection on shoot elongation and production of dry matter. Agron. Abstr. p. 17-18.

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