A STUDY OF QUANTITATIVE CHARACTERS
IN TWO CROSSES OF
SORGHUM

By

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INTRODUCTION

The importance of sorghum in the economy of the world can well be recognized by its vast distribution, mass production and varied utilization. In the United States of America grain sorghum production is only exceeded by wheat and corn. Grain sorghums are used as a feed for poultry, cattle, sheep, and swine (26)[1]. Outside the United States grain sorghum is consumed by human beings. In most parts of Africa, China and India it is an important cereal for human consumption. Grain sorghums are grown throughout Oklahoma and especially in the western half of the state.

Sorghum improvement has received considerable attention for many years. Early efforts of sorghum breeders were directed toward testing of plant introductions and selections of adaptable types from them. Later, hybridization was recognized as a means of creating variability within which to select for combinations of characters not previously available. The vigor of first generation sorghum hybrids was studied by early workers. They attributed the increased yield of hybrids to hybrid vigor (9).

Hybrid vigor or heterosis has been explained as a phenomenon in which the performance of the hybrid is better than the average performance of the parents or of the better parent. The genetic explanations of this phenomenon are based on hypotheses such as heterozygosity of

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[1]Figures in parentheses refer to literature cited.

the material, dominance and interaction of different dominant genes.

The main objective of this investigation was to study quantitative characters in two crosses of grain sorghums. Ten quantitative characters were studied on equally spaced individual plants of parents, hybrid and F_2 generation. Heritability estimates were made by using F_2 variance method and associations of characters in the F_2 generation were determined by calculating simple correlation coefficients.

REVIEW OF LITERATURE

Studies on quantitative characters are not recent. The phenomenon of quantitative inheritance was recognized long before Mendel and breeders have been working with quantitative characters for thousands of years (33). So much has been written on the inheritance of quantitative characters and hybrid vigor that only the literature which has direct bearing on this problem will be reviewed.

Measureable differences in degree rather than in kind are defined as quantitative characters. There is a continuous range of variability in the inheritance of these characters which are highly influenced by environment. Many genes are involved in the expression of quantitative characters, so that simple genetic explanations on the basis of one or two segregating genes is usually not possible (30, 33). As reported by Smith (30) in his review on inheritance of quantitative characters in plants, East and Nelson Ehle interpreted the continuous variability in quantitative characters as being due to numerous genes which are similar and relatively small in effect with incomplete dominance and which act in a cumulative manner. This genetic explanation of the continuous variability of quantitative characters is well known as the "multiple factor hypothesis". Although this is an accepted hypothesis, some modifications to this interpretation have been suggested. Multiple alleles at one locus or closely linked loci are believed to take part in the hereditary phenomenon of quantitative characters (30). Hutchinson et al. (16) have interpreted the differences in leaf shape in Asiatic cotton on the basis of multiple allele concept. There are quantitative characters which are controlled by relatively few genes, as plant height in maize (30).

Heterosis or hybrid vigor is a phenomenon in which the hybrid or F_1 generation performance is superior to the better parent or at least exceeds the mean of the two parents (14). Hybrid vigor was first studied by Kolreuter in 1763 (28). Since then there has been a continuous interest in this phenomenon as it affects all plants and animals. Interest in hybrid vigor arose when genetic knowledge was very meager. The main interest in heterosis which attracted the attention of most scientists was the vigorous hybrid produced when inbred lines were crossed. It was assumed that hybrid vigor was due to unlike genes at certain loci, but no proof was given (14).

There is a close relation between quantitative characters and hybrid vigor. As described by Sprague (32),

> If the F_1 hybrid between two lines or varieties is intermediate between the two parents and if the F_2 generation exhibits a continuous array of variation, it is customary to speak of the differences involved as being inherited quantitatively. If, on the contrary, the F_1 hybrid exceeds the larger parent, the increase in total growth is generally ascribed to hybrid vigor or heterosis, regardless of the type of segregation observed in the F_2.

East (11) explained, "The key to heterosis is the inheritance of quantitative characters" and interpreted heterosis through the behavior of "normal" allelomorphic series. Hayes et al. (14) suggested "hybrid vigor as one phase of quantitative inheritance". Smith (30) stated, "It is reasonable to consider heterosis as one type of result in the general category of quantitative inheritance."

Hybrid vigor is believed to be a phenomenon of gene action. The widely accepted explanation of hybrid vigor was proposed by Jones (17) in 1917 who explained vigor in hybrids as being due to their heterozygosity, assuming dominance, where the deleterious recessives are masked by the dominant alleles. To replace the term "heterozygosis", G. H. Shull (29) in 1914 proposed the term "heterosis". The terms hybrid vigor and heterosis are synonyms. Whaley (43) in 1944 remarked that heterosis had been erroneously used in the literature in place of hybrid vigor and tried to differentiate between these two terms. But his interpretation has not received wide acceptance and Hayes, Immer and Smith (14) pointed out that the use of the term heterosis as a synonym for hybrid vigor was highly desirable. Srb and Owen (33) in 1958 used the term heterosis interchangeably with hybrid vigor. In 1948 Shull (28) gave a detailed explanation of his proposed term, heterosis, and stated that decrease in vigor should not be termed as negative heterosis as it is a completely different phenomenon.

Ashby (2) investigated the physiological nature of hybrid vigor in maize. Growth curves and photosynthesis efficiencies of leaves were studied. He found that hybrids were no better than parents. The hybrid had only an advantage of increased percentage of germination, which he stated was due to the initial advantage of an increased size of embryos. He concluded that, "hybrid vigor in these strains is nothing more than the maintenance of an initial advantage in embryo size." This statement was criticized by East (11) in 1936. He debated that heterosis was found in hybrids whose seeds were not larger than those of the parents, and there was no correlation between seed size and growth of the plants. Increased seed size was a manifestation of hybrid vigor. He also concluded that heterosis was genetically controlled and found that the vigor was maintained in the amphidiploids which bred true. It was also stated that heterosis increased with genetic disparity.

GENETIC INTERPRETATIONS OF HETOROSIS

The heterozygous state, as proposed by Jones (17) is the basic interpretation to explain the genetic mechanism of heterosis. This interpretation was based on the dominance of linked genes and generally has been called the "dominance of linked genes hypothesis."

East (11) in 1936 gave another explanation which was based on the interaction of alleles and lack of dominance. He explained that if allele A_1 effects a different physiological condition than allele A_2 then A_1A_2 is more vigorous than either of the homozygotes A_1A_1 and A_2A_2. The phenomenon was designated as "overdominance" by Hull (15). In this explanation heterozygosity is present and dominance is lacking. It could also be explained as a complimentary action between two alleles, A_1 and A_2.

The third genetic explanation of heterosis is based upon the interaction of different dominant genes. For example, if two inbreds of the following genetic constitution are crossed, the F_1 generation is vigorous and illustrates the interaction of different dominant genes resulting in a vigorous hybrid.

mmNNOOppQQ x MMnnOOPPqq

MmNnOOPpQq

When the F_1 is selfed or backcrossed there should be a few genotypes having dominant genes at all loci. Such homozygous true-breeding lines were not found (33).

Hybrid vigor is manifested in various ways in different organisms under different conditions. As reported by Whaley (43), Kolreuter explained hybrid vigor as being the greater size of plants, increased number of flowers and general vegetative vigor. Coffman (8), while studying oat hybrids found heterosis in different parts of the plants in different crosses of oats. Jones, as reported by Whaley (43) recorded the manifestation of heterosis in maize by increased total yield, height, length of ear, number of nodes per plant, number of grains per row, increased root length, diameter and increased penetration by F_1 hybrids. The overall explanation of the manifestation of heterosis by East (11) was,"invariably it is something which effects the organism as a whole." Hence, no fixed key can be followed in explaining hybrid vigor, as it is manifested in a variety of ways.

Hybrid vigor in sorghum was first reported by Conner and Karper (9) in 1927. The main obstacle in the way of seed production of hybrid sorghums was the self-fertilized nature of the sorghum plant with complete flowers. A genetically male sterile plant in sorghum (Sudangrass) was first found by Stephens in 1929. It was reported in 1936 by Karper and Stephens (20). In 1935 Stephens (34) found another genetically sterile (ms_2) plant. As reported by Stephens et al.(36) a genetic male-sterile was found in Day variety by Glen H. Kuykendall in 1943. This male-sterile plant when pollinated by some varieties produced F_1 plants which were also male sterile but when pollinated with certain other varieties produced fertile hybrids. A plan of a three-way cross for the production of hybrid seed by using this male sterile line was proposed.

Stephens and Holland (37) reported the discovery of cytoplasmic sterility and proposed its use in hybrid sorghum seed production. They concluded that this male sterility which was a result of interaction between Milo cytoplasm and Kafir nuclear genes should provide a more satisfactory way of producing hybrid sorghum seeds than the three-way cross, in which only genetic male sterility was utilized. At present, several cytoplasmic male sterile lines have been established for use in hybrid sorghum production.

Conner and Karper (9) made three crosses of sorghums with each variety having a distinct height. The F_1 hybrids were found to be 66 percent taller than the tallest parents and the F_2 generation was also 40 percent taller than the tallest parents. Heterosis was observed in leaf size, chlorophyll development, and grain yield. Maturity was also markedly delayed.

Karper and Quinby (21) in 1937 conducted a study of hybrid vigor in sorghums. Observations on growth, maturity, yield of grains, yield of forage, and other characters were made. It was concluded that all the hybrids were more vigorous than the parents. The most evident expression of hybrid vigor was increased vegetative growth and extreme lateness of maturity. The recorded range of vigor varied from a slight increase over the parents to an extreme height of plants 15 feet tall and grain yields above 150 bushels per acre. While studying the nature of gene action it was concluded that the sorghum varieties were different in genetic make-up for many genes other than those that are visible in their effect and it was interpreted that hybrid vigor was mainly due to the accumulation of dominant favorable genes in the hybrids over their parents.

Bartel (3) in 1949 reported studies on hybrid vigor of sorghum. Altogether nineteen hybrids were studied out of which sixteen hybrids were higher yielding than the parents. Almost all hybrids had more leaves. Fifteen hybrids yielded more stover than the means of the parents. The average seed size was intermediate or as large as the larger parent.

Stephens and Quinby (35) reported on the grain yield of hybrid sorghum. The seeds were produced each year by hand pollination of male-sterile Texas Blackhull kafir with Day selection G.C. 38311. The hybrids yielded 10 percent more than the higher parent and 27 percent more than the average of all varieties in April planting. From June plantings the hybrids yielded 20 percent more than the higher parent and 44 percent more than the average of all varieties. The hybrids also exceeded the parents in tillering and in threshing percentage, but were intermediate in height, maturity, lodging, seed color, resistance to Chinch bug and Charcoal rot disease.

Quinby and Karper (25) in a study of heterosis in sorghum which resulted from the heterozygous condition of a single pair of genes, "Mama", reported that their heterozygous condition was responsible for late maturity as compared to either of the homozygotes. The number of stalks, head weight, and stover weight were also greater in the heterozygotes. It was concluded that the increase was due to the late maturity resulting in the long period of growth.

Bhatti and Khan (5) in 1953 reported from Pakistan a study of heterosis in sorghum hybrids. The hybrids between T100 x T20 and T100 x Sudangrass resulted in marked hybrid vigor. The hybrid of the latter cross exceeded the higher parent in plant weight by as much as 333 percent.

Argikar and Chavan (1) from India in 1958 studied hybrid vigor in eleven hybrids. Heterosis was observed in plant height, girth of stem, number of internodes per plant, length and breadth of leaf, length and diameter of panicle, seed yield and weight of 100 seeds. It was concluded that the increase in yield was due to increased seed number per panicle rather than increased seed size.

HERITABILITY OF CHARACTERS

The transmissibility of a particular character from generation to generation may be defined as heritability and it can be estimated by appropriate calculations. Heritability is of importance in plant breeding as a measure of selection efficiency in segregating populations. These estimates indicate to a breeder how much variation in segregating populations is due to environment and how much variation is due to genetic differences.

Various methods and formulae have been devised for calculating the estimates of heritability of characters. Warner (40) in his review of heritability in 1952 grouped the previous methods of estimating heritabilities into three main classes which are as follows: (1) Parent-offspring regression; (2) Variance components from an analysis of variance; (3) Approximation of non-heritable variance from genetically uniform population to estimate total genetic variance. While arguing that the above methods were not satisfactory for plant breeders who need an early generation estimate of heritability he proposed a new method and explained its advantages as, "(1) The estimate is made entirely on the basis of the F_2 and the backcross of the F_1 to each inbred parent. (2) The estimating of non-heritable variance is unnecessary." He presented a formula for estimating heritability in which it was assumed that the environmental component of variance of F_2 and the backcross are comparable in magnitude. The additivity of genetic effects, lack of epistasis and independence of genotype and environmental variance is also assumed.

As reported by Warner (40) the first studies on heredity and environmental variation were made by Johannsen, East and Nilson-Ehle in 1909, 1916, and 1909, respectively. Fisher in 1918 studied the genetic variance in relation to environmental effects. He demonstrated that the genetic variance was due to additive effects of genes, due to dominance deviations from the additive scheme, and due to deviations from the additive scheme attributable to interaction of nonallelic genes. He also reported that Charles, Smith and Powers in their study of genetic and environmental variance used the variance of non-segregating population as a measure of environmental variance and separated genetic variance from total variance. Heritable variation was studied by various other workers who partitioned the variances due to additive genetic effects and due to deviations from the additive scheme (40).

Robinson, et al. (27) in 1952 studied heritability and degree of dominance in corn. They divided the genetic variance into additive genetic variance and variance due to dominance deviation. The bi-parental progenies were studied to estimate the components of variance and heritability in corn. This method was also compared with the method of estimating heritability by use of parent-offspring regression. High estimates of heritability were obtained for plant height, ear length, husk extension and husk score. Yield, number of ear per plant, ear height and ear diameter had very low heritability estimates.

Mahmud and Kramer (23) while studying the segregation for yield following a soybean cross estimated the heritability for yield, height and maturity by using F_2 variance method, the regression of F_3 progeny means on F_2 plant values and variance among progenies as derived from variance components of analysis of variance. The heritability estimates ranged from 69 to 77, 74 to 91, and 92 to 100 percent, respectively.

Kalton, et al. (19) in 1952 estimated the ratio between genetic variance and total variance in Orchardgrass clones by using the differance between the variances of inbred and progenies and dividing by total variance of progeny. The variance of inbreds was attributed only due to environment. Heritability estimates of spring vigor score, leafiness score, plant height, panicle number and yield varied from 35 to 56 percent. Estimates of heritability for yield and panicle number were negative or very low.

Weber and Moorthy (41) in 1952 calculated estimates of heritability in soybean crosses as a percent of genotypic variance of the total F_2 variance. In two crosses the heritabilities for yield were -78. and -1.7 percent. Estimates for other agronomic characters ranged from 13 to 86 percent. High heritability estimates were obtained for flowering time and maturity date. They interpreted that;

> It should not be forgotten, however, that heritability calculated from F_2 data is the genic portion of an attribute plus the effects of dominance and epistasis, while that calculated from reciprocal regression is largely due to additive genetic effects transmitted from parent to progeny such as $F_2 - F_3$. The method used herein would be useful in calculating heritability for any character or the genotypic correlations between any two characters from F_2 data.

Bartley and Weber (4) in 1952 reported a study of heritability of four agronomic characters in three soybean crosses from the relations of F_2 and F_3 generations to F_3 to F_4. Heritability estimates were calculated by regression of progeny means on their parents in the F_2

and F_3 generations. Average heritabilities ranged from 10.9 to 92 percent. Estimates for yield and lodging were low and variable and for maturity and plant height were fairly high.

The genetic and environmental variability in two crosses of barley was reported by Fiuzat and Atkins (12) in 1953. F_2 variance method as described by Weber and Moorthy (41) was followed to estimate heritability of six agronomic characters. Earliness and plant height were found to be highly heritable and it was concluded that individual plant selection in F_2 for these characters will be effective. Heritability values ranged from 21.2 percent for kernel weight of cross 2 to 92.1 percent for heading date in cross 1.

Barton and DeVane (7) in 1953 reported a method of estimating heritability while working with the Tall fescue. They explained its advantages as it does not require the assumption that environmental variance is equal in both segregating and non-segregating populations and it also reduces the amount of genotype x environmental variance carried in the estimate of genetic variance.

Keller and Likens (22) in 1955 estimated the heritability of characters in Hops by the procedure outlined by Barton and DeVane (7). Estimates of heritabilities and expected gains from selections were calculated from single-plot and replicated basis.

Heritability ratios were used by Thomas and Kernkamp (39) for measuring combining ability with Smooth broomgrass. Estimates of heritability were calculated as a ratio between genetic variance obtained from the difference of mean squares of progenies and error mean square to total variance from analysis of variance.

Jogi (18) in 1956 proposed a formula for estimating heritabilities by using advanced generation materials in two barley crosses. Heritability for disease reaction and other agronomic characters were calculated by using the components of analysis of variance, which ranged from 42 to 96 percent.

Frey and Horner (13) in 1957 proposed a modified parent-progeny regression procedure for estimating heritability in oats. A comparison was made in the heritability estimates obtained from conventional method and proposed a standard unit method. This method has a heritability ceiling of 100 percent, whereas the ceiling varies in conventional method.

Literature on the heritabilities of characters in sorghum was not found, therefore it is not included in the review of literature.

CORRELATION OF CHARACTERS

It is of interest and use in plant breeding to know the degree of association of two characters. It helps a breeder to select a character and predict the performance of another related character. Literature on association of characters in sorghum was not available. Most of the studies on correlation of morphological characters were conducted in corn and wheat crops. Bunch (6) in 1956 studied the correlations of various morphological characters in corn and reviewed the literature on the previous work.

Weibel (43) in 1955 studied the correlation, in wheat crop and a vast review of literature has been presented on the previous studies of correlation in that crop.

MATERIALS AND METHODS

Crosses were made between the varieties Redlan male sterile and Plainsman restorer and between Combine kafir 60 male sterile and Combine 7078 in 1956. The hybrids of these two crosses were grown in 1957 and seeds of all the parents, their F_1 and F_2 were produced under bags to insure selfing. These seeds were available in the Sorghum Project, Agronomy Department, Oklahoma State University. A study of quantitative characters in sorghum was undertaken at the Oklahoma State Agricultural Experiment Station Farm at Perkins, during the summer of 1959. Following are the brief descriptions of the sorghum varieties used as parents in the two crosses.

Redlan is a combine grain sorghum released by the Oklahoma Agricultural Experiment Station in 1952. The average height of plants ranged from 38.2 inches at Woodward to 43.5 inches at Stillwater. The plants mature in 118 to 120 days. Tillers are rarely produced. The stems are sturdy and bear kafir-like heads. The seeds are large and reddish-yellow in color (10).

Plainsman was developed from the Texas Agricultural Experiment Station. It has long and cylindrical heads resembling kafir. It blooms in 70 days and matures in 110 days. It is resistant to milo disease, tillers only occasionally, and has medium sized reddish-yellow grains (24).

Combine kafir-60 is an early combine type Blackhull kafir. The stalks are juicy and stand up well in the field (24). The head is erect with white colored seeds. This variety blooms in 60 days, a week earlier than the Plainsman. The test weight of the grain averages 60 pounds per bushel.

Combine 7078 was also developed in Texas. It blooms in about 62 days. The grain is soft, milo yellow colored and it weathers very badly in wet seasons (24). Lodging is common but grains may be produced even in dry seasons.

The experiment was conducted in a randomized complete block design with four replications. There were eight entries in each replication consisting of four parents, two F_1 hybrids and two F_2. For parents and the F_1 hybrid, the plots were made up of three rows, 40 inches apart and 20 feet long with a four-foot alleyway between the replications. To have a more precise measure of the F_2 segregating population, the plot size was increased to six rows.

The experiment was sown on June 30, 1959, with a tractor-drawn planter equipped with funnels through which the seeds were dropped by hand into the planting shoes. After emergence the rows were thinned leaving only one plant every 18 inches. When the plants were nearing the heading stage, fifteen plants in the middle row of each plot of the parents and of the F_1 hybrids were tagged. Sixty plants of the F_2 population from the middle four rows were tagged in each plot by selecting fifteen plants in each row. These plants were selected starting from the end and proceeding with equally competative plants.

The following pre-harvest observations were recorded on each plant tagged:

1. Days to first bloom: Number of days from planting to the first day of anthesis.

2. Male sterility: Plants which failed to shed pollen at anthesis. In the F_2 populations it was expected that approximately one-fourth of the plants would be male sterile. The parents and F_1 hybrids were fully fertile.

3. Plant height: Distance in inches from the ground level to the top of the matured head.

4. Head length: Distance from the base to the tip of the head in inches.

5. Number of tillers: Number of heads produced by each plant. The test was harvested on November 21, 1959, by hand. To avoid the loss of seeds in handling and transportation after harvest, each head was covered with a paper bag. The following post-harvest observations were recorded on individual heads harvested.

6. Head weight: Individual weight of heads in grams before threshing. To avoid variation in head weight due to peduncle, the latter was cut-off to a length of 4 to 5 inches in all the heads before weighing.

7. Grain yield: Weight of grain in grams after threshing of head. Threshing was done by a power driven small thresher.

8. Threshing percentage: The percentage figure calculated by dividing grain weight by the head weight and multiplying by 100.

9. Weight of 100 seeds: Weight of 100 seeds selected at random and weighed to the nearest milligram.

10. Number of seeds per plant: A figure calculated by dividing weight of threshed grain by weight of 100 seeds and multiplying by 100.

11. Bushel weight: Estimate of the weight of a bushel of grain based on method of Swanson (38).

12. Protein content: Percentage of protein contained in each parent, F_1 and F_2, analysed by standard Kjeldahl procedure. The sample for chemical analysis was made up from a composite of all the heads in any one variety or other generations.

The frequency distribution histograms of all the characters except of protein content were made for each parent, F_1 hybrid, and F_2 generation.

The data collected for each plant was punched on I.B.M. cards and sums of squares and sums of cross products were obtained by machine. The combined analysis of variance for parents and F_1 was calculated for both crosses (42). In this analysis of variance, treatment and error sums of squares and degrees of freedom were partitioned and comparisons were made between the parents and between parents and F_1. Homogeneity of error variance was tested by the respective components of error variance and within variance was obtained for parents and F_1 populations.

Estimates of heritability were obtained by using F_2 variance as indicated by Weber and Moorthy (41). Variance within varieties was subtracted from the total F_2 variance and the fraction obtained was divided by F_2 variance. This quotient was multiplied by 100 to give the estimate of heritability in percentage.

The association of different characters was determined by calculating correlation coefficients as explained by Snedecor (31).

RESULTS AND DISCUSSION

For ease of presentation of results, the cross between Redlan and Plainsman is designated as cross 1 and the cross between Combine kafir-60 and Combine 7078 as cross 2.

Results and discussions are presented in the following order: (1) Frequency distribution histograms, means and ranges of each parent, F_1 hybrid and F_2 generation of cross 1 and cross 2, respectively, for each character studied, and their analysis of variance; (2) Heritability estimates of agronomic characters; and (3) Correlation of characters. The following is the order of characters studied and presented in this section: (1) Days to first bloom; (2) Male sterility; (3) Plant height; (4) Head length; (5) Number of tillers; (6) Head weight; (7) Grain yield; (8) Threshing percentage; (9) Weight of 100 seeds; (10) Number of seeds per plant; (11) Bushel weight; and (12) Protein content.

Days to first bloom: Sampled frequency histograms, means and ranges of parents, F_1 hybrid and F_2 generation for days to first bloom for cross 1 are presented in Figure 1. The histograms of Redlan and Plainsman showed a bimodal distribution. The means of these two parents were similar, being 65.7 days. There was a difference of one day in the ranges with all the plants blooming with a range of fifteen to sixteen days. The mean of the F_1 for days to first bloom was 2.8 days earlier than the parents. Although the range of the F_1 population was almost the same, the plants started blooming earlier than the parents and

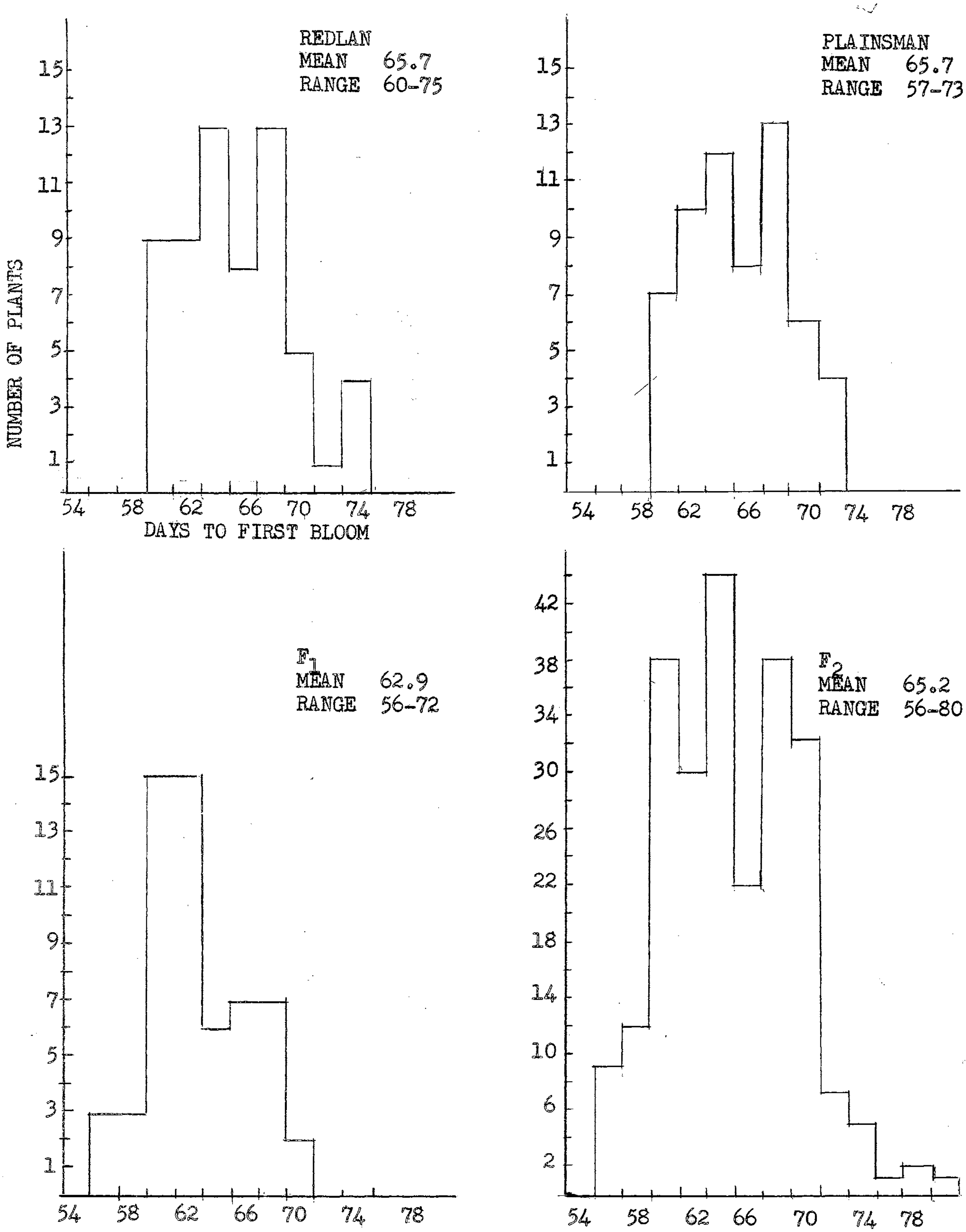


Figure 1. Frequency histograms, means and ranges of days to first bloom for the parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman

completed blooming in sixteen days. The F_2 mean value was almost like the parents with a wide range of twenty-four days. The wide range in F_2 was expected but such a difference between the parents and F_2 might be due, in part, to the greater number of plants observed in this generation.

The combined analysis of variance for parents and F_1 for days to first bloom of cross 1 is given in Table I. The difference between the F_1 and parents, as indicated by "F" ratio, is not significant. It appears that this character is affected by a number of genes. The hybrid was a few days earlier which may be due to an accumulation and interaction of some favorable genes transmitted through the parents.

Figure 2 represents the sampled frequency distribution histograms, means, and ranges of cross 2 for days to first bloom. There was more variation in Combine kafir-60 which is evident from the ranges. Both the parents took sixty-eight days on an average for the first blooming. The mean of the F_1 hybrid was four days earlier than the parents, and the mean of the F_2 was one day earlier than the parents. The range of the F_2 population was larger than the parents and the F_1 hybrid.

Analysis of variance for days to first bloom for cross 2 is given in Table II. The difference between the parents and F_1 was significant at the 5 percent level. Early blooming of hybrids in both the crosses was possibly due to an increased rate of growth.

Male sterility: All the plants studied in parents and F_1 generations of the two crosses were male fertile. Male sterile plants were found in the F_2 generations. This was expected due to the male sterile parents, Redlan in cross 1 and Combine kafir-60 in cross 2, which were crossed with restorers Plainsman and Combine 7078, respectively. In the

TABLE I

Analysis of variance of individual plant data for days to first bloom for the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	2782.66	
Replications	3	342.28	114.09
Varieties	2	315.47	157.73
P_1 vs. P_2	1	0.01	0.01
F_1 vs. $P_1 + P_2$	1	315.45	315.45
Reps x Varieties (Error)	6	639.10	106.51
Reps x (P_1 vs. P_2)	3	474.28	158.09
Reps x (F_1 vs. $P_1 + P_2$)	3	164.82	54.94
Within Varieties	168	1484.77	8.83
P_1	56	508.53	9.08
P_2	56	477.22	8.52
F_1	56	499.12	8.91
F_2	224	3341.42	14.91

TABLE II

Analysis of variance of individual plant data for days to first bloom for the parents and F_1 of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	2350.80	
Replications	3	30.13	10.04
Varieties	2	650.00	325.00*
P_1 vs. P_2	1	1.88	1.88
F_1 vs. $P_1 + P_2$	1	648.11	648.11*
Reps x Varieties (Error)	6	325.07	54.17
Reps x (P_1 vs. P_2)	3	235.65	78.55
Reps x (F_1 vs. $P_1 + P_2$)	3	89.42	29.80
Within Varieties	168	1345.62	8.00
P_1	56	545.46	9.74
P_2	56	207.59	3.70
F_1	56	592.52	10.58
F_2	224	3664.35	16.35

* Significant at the 5 percent level.

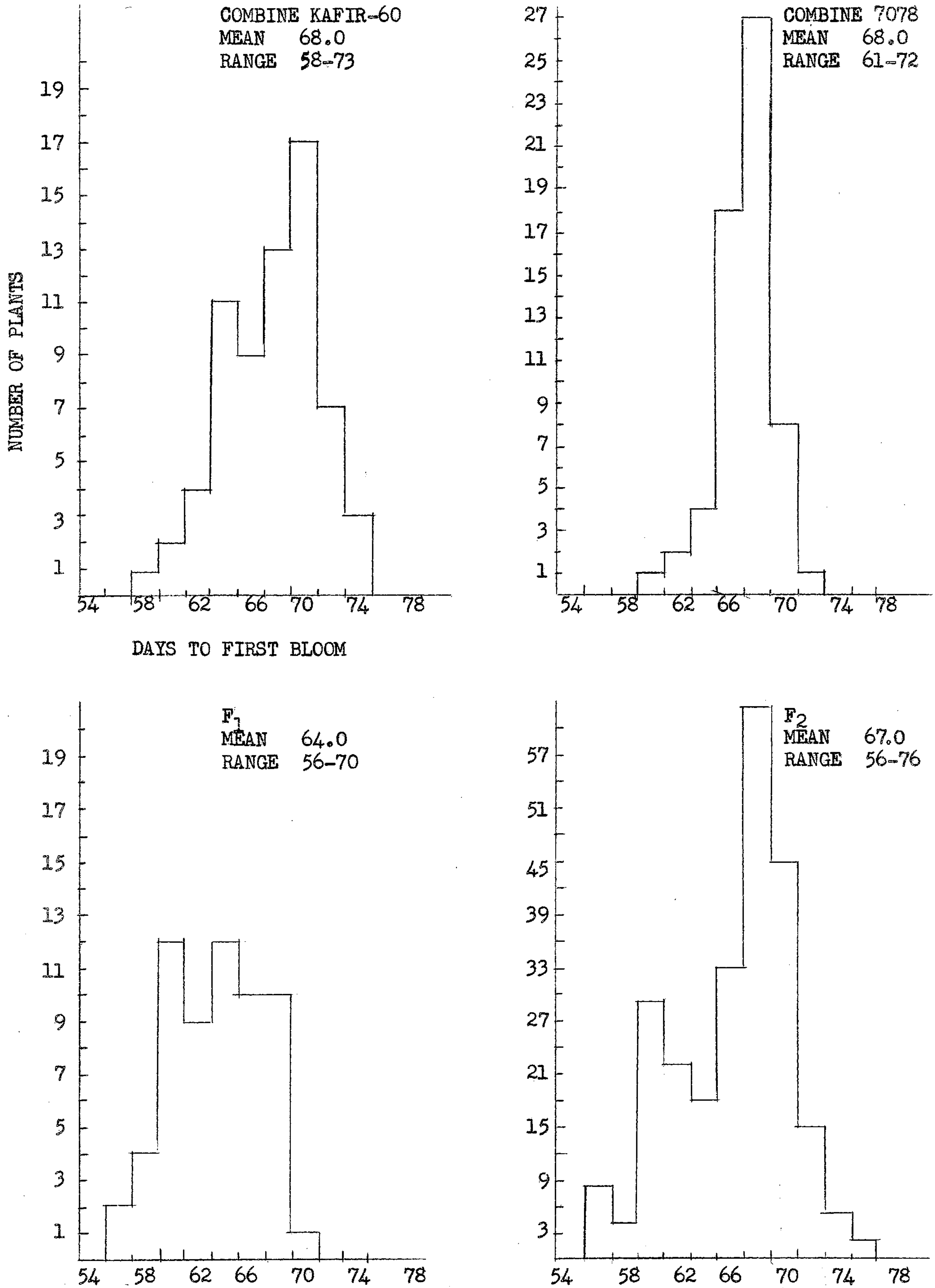


Figure 2. Frequency histograms, means and ranges of days to first bloom for the parents, F_1 and F_2 generations of cross 2, Combine kafir-60 x Combine 7078

F_2 generation of cross 1, out of 240 individuals, 61 were male sterile and in the F_2 of cross 2, 55 plants of the 240 were male sterile. This was a close approximation of 3:1 ratio between male fertile and sterile plants, respectively. The chi-square value for cross 1 was 0.022 and for cross 2 it was 0.54 indicating a good fit to the 3:1 ration. These chi-square values were not significant at the five percent level. This ratio indicates the possibility of single factor control of male sterility. The gene for male fertility is dominant over its allele which, when homogyzous,produced male sterile plants in F_2 segregating populations of both the crosses. After studying this male sterility a logical question arose as to whether there might be differences, between male fertile and male sterile plants for the characters studied. The discussion of this will be presented later.

Plant height: Sampled frequency histograms, means and ranges of parents, F_1 and F_2 of cross 1 for plant height are presented in Figure 3. As indicated by mean height of parents, Redlan was 5.4 inches taller than Plainsman. The mean of the F_1 hybrid and the F_2 segregating population was intermediate between the two parents, and there was a continuous variation in F_2 generation. These frequency distributions and means for plant height of cross 1 took a form that is generally expected for characteristics quantitatively inherited.

Table III represents the combined analysis of variance of plant height for parents and F_1 of cross 1. The difference in height of the parents was significant and the difference between F_1 hybrid and parents was not significant.

Figure 4 contains the sampled frequency distributions, means, and ranges for the parents,F_1 and F_2 of cross 2 for plant height. The

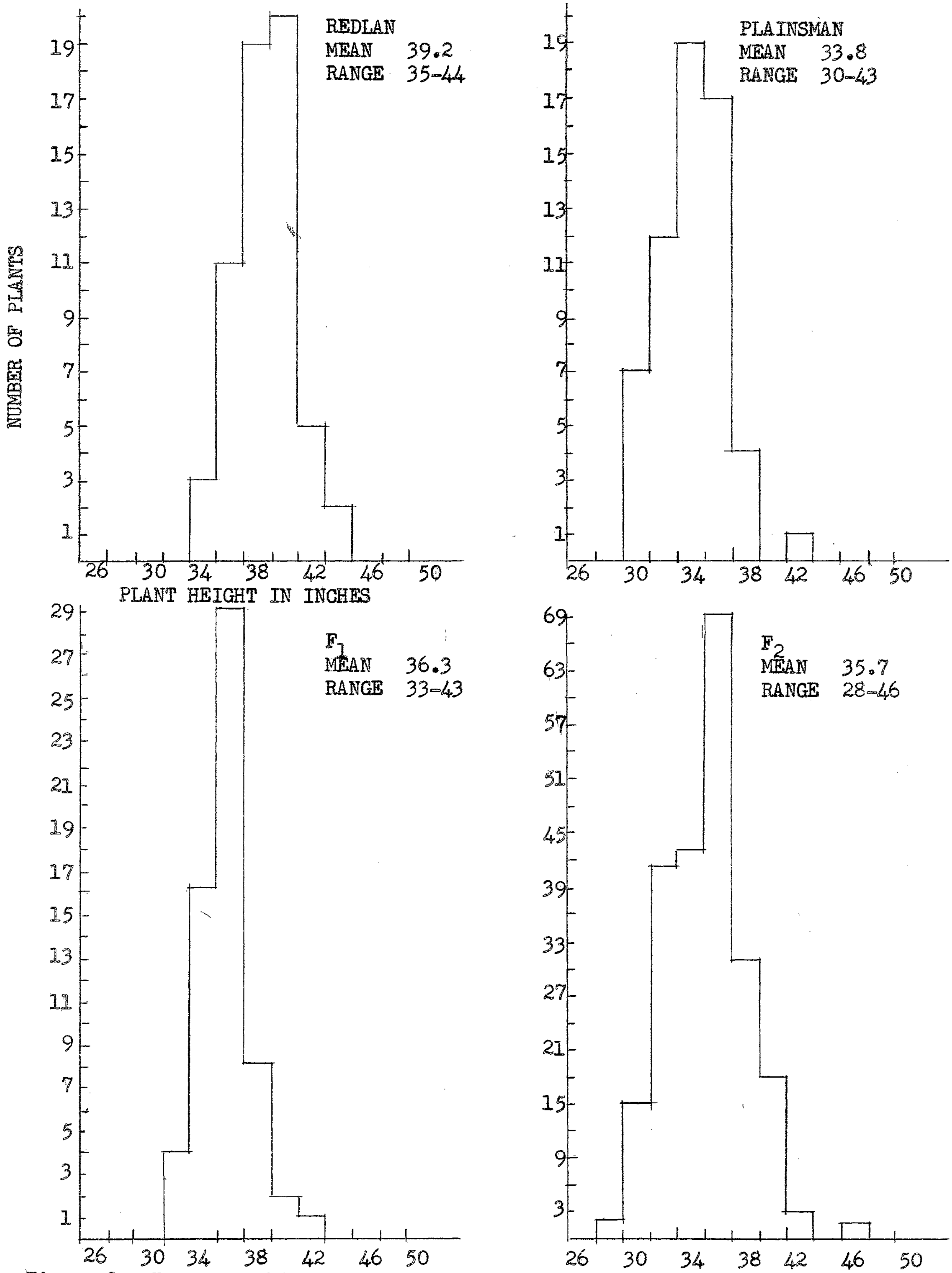


Figure 3. Frequency histograms, means and ranges of plant height for the parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman.

TABLE III

Analysis of variance of individual plant data for plant height of the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	1711.92	
Replications	3	15.87	5.29
Varieties	2	893.75	446.87**
P_1 vs. P_2	1	891.08	891.08**
F_1 vs. $P_1 + P_2$	1	2.67	2.67
Reps x Varieties (Error)	6	62.29	10.38
Reps x (P_1 vs. P_2)	3	12.16	4.05
Reps x (F_1 vs. $P_1 + P_2$)	3	50.13	16.71
Within varieties	168	740.0	4.40
P_1	56	320.79	5.72
P_2	56	250.79	4.47
F_1	56	168.39	3.00
F_2	224	1927.56	8.60

TABLE IV

Analysis of variance of individual plant data for plant height of the parents and F_1, of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	1662.55	
Replications	3	65.21	21.73
Varieties	2	743.63	371.81**
P_1 vs. P_2	1	603.01	603.01**
F_1 vs. $P_1 + P_2$	1	140.61	140.61**
Reps x Varieties (Error)	6	39.08	6.51
Reps x (P_1 vs. P_2)	3	22.70	7.57
Reps x (F_1 vs. $P_1 + P_2$)	3	16.37	5.45
Within varieties	168	814.63	4.83
P_1	56	238.39	4.25
P_2	56	145.19	2.59
F_1	56	431.06	7.69
F_2	224	4027.84	17.98

** Significant at the 1 percent level.

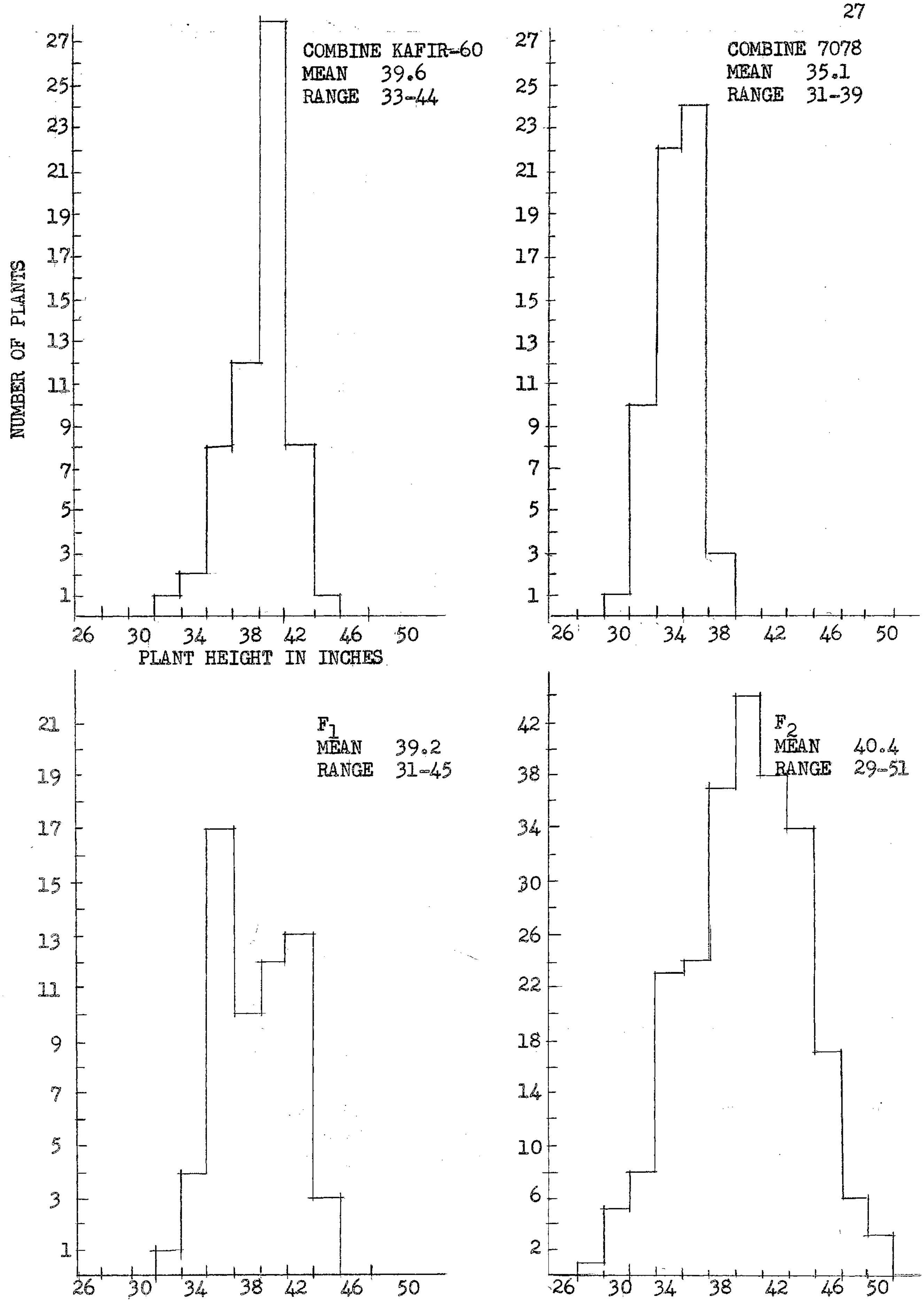


Figure 4. Frequency histograms, means and ranges of plant height for the parents, F_1 and F_2 generations of cross 2, Combine kafir-60 x Combine 7078.

parents Combine kafir-60 and Combine 7078 can be differentiated into two distinct groups, former being the taller and latter being the shorter. The mean of the first generation hybrid was similar to that of the taller parent and there was a difference of about two inches between the mean of the parents and of the F_1 hybrid. The F_1 had a wider range than the parents. The F_2 population mean was about one inch greater than the taller parent with a very wide range of 22 inches between the shortest and the tallest plant. The large variation in F_2 appears to be due to recombinations and the effect of environment. In this cross the genes controlling the height of the taller plant parent have exhibited dominance.

A highly significant difference in plant height was found between the parents and between the parents and the hybrid of cross 2. The analysis of variance is shown in Table IV. Highly significant differences between parents and hybrid and among parents were due in part to the reduced error variance.

Head length: Sampled frequency distributions, means, and ranges of head length for cross 1 are reported in Figure 5. There were very little differences between the mean head lengths of parents, F_1 and F_2 generation. The frequency distribution of Plainsman appeared to be bimodal. The F_1 hybrid and F_2 population followed the distribution of Redlan with similar means. It appears that there was a partial dominance of long head length.

Analysis of variance of head length for cross 1 which is given in Table V, does not indicate any significant differences.

Mean head length of cross 2 for parents, F_1 and F_2 are given in Figure 6. Combine kafir-60 had longer heads than Combine 7078. The

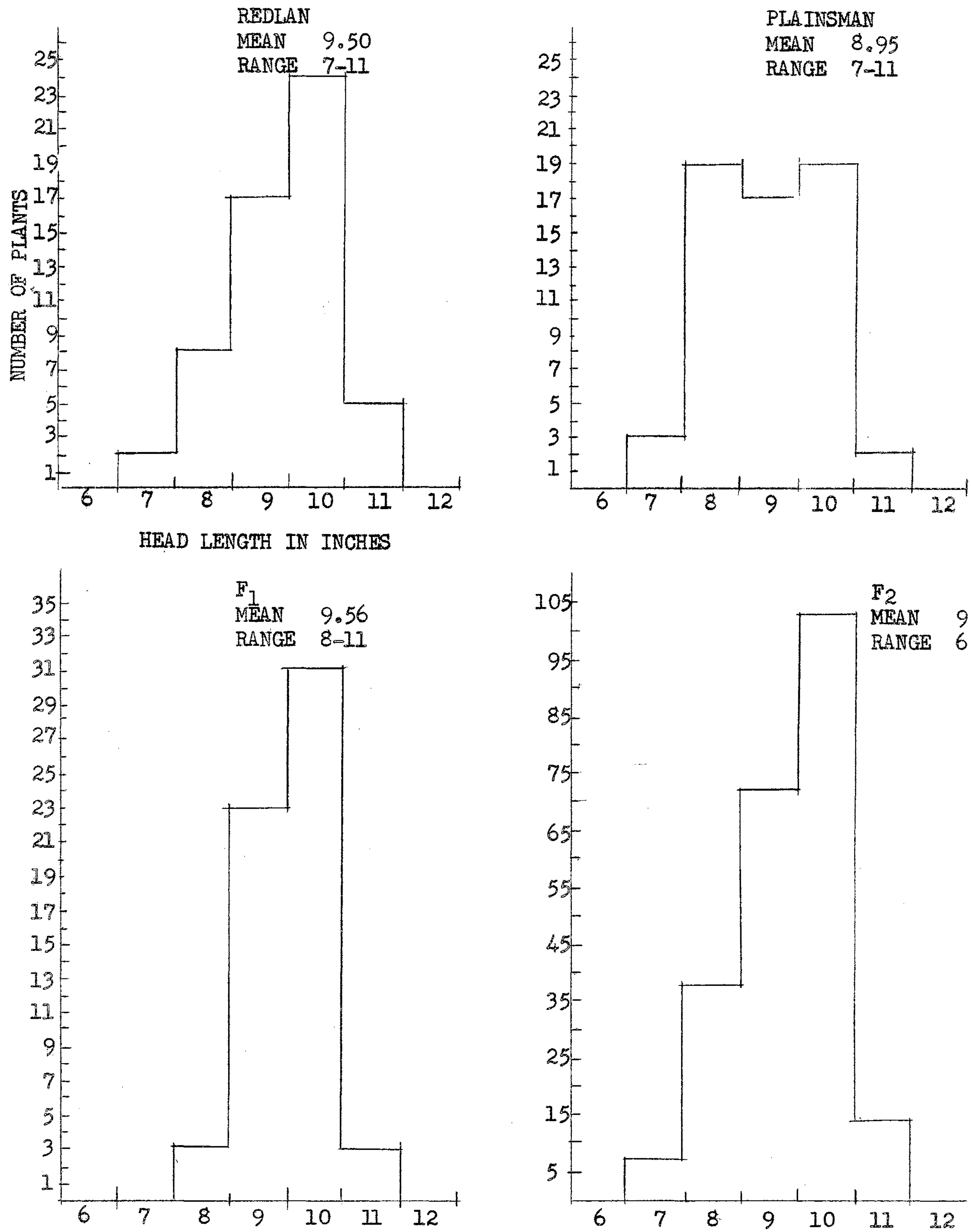


Figure 5. Frequency histograms, means and ranges of head length for the parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman.

TABLE V

Analysis of variance of individual plant data for head length of the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	142.33	
Replications	3	13.48	4.49
Varieties	2	13.74	6.87
P_1 vs. P_2	1	9.09	9.09
F_1 vs. $P_1 + P_2$	1	4.65	4.65
Reps x Varieties (Error)	6	12.44	2.07
Reps x (P_1 vs. P_2)	3	9.01	3.00
Reps x (F_1 vs. $P_1 + P_2$)	3	3.43	1.14
Within varieties	168	102.67	0.61
P_1	56	41.32	0.73
P_2	56	36.26	0.64
F_1	56	25.06	0.44
F_2	224	178.5	0.79

TABLE VI

Analysis of variance of individual plant data for head length of the parents and F_1 of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	158.8	
Replications	3	9.11	3.03
Varieties	2	42.63	21.31**
P_1 vs. P_2	1	15.41	15.41*
F_1 vs. $P_1 + P_2$	1	27.22	27.22**
Reps x Varieties (Error)	6	10.39	1.73
Reps x (P_1 vs. P_2)	3	5.55	1.85
Reps x (F_1 vs. $P_1 + P_2$)	3	4.84	1.61
Within varieties	168	96.67	0.57
P_1	56	41.33	0.73
P_2	56	30.66	0.54
F_1	56	24.66	0.44
F_2	224	216.76	0.96

* Significant at the 5 percent level.
**Significant at the 1 percent level.

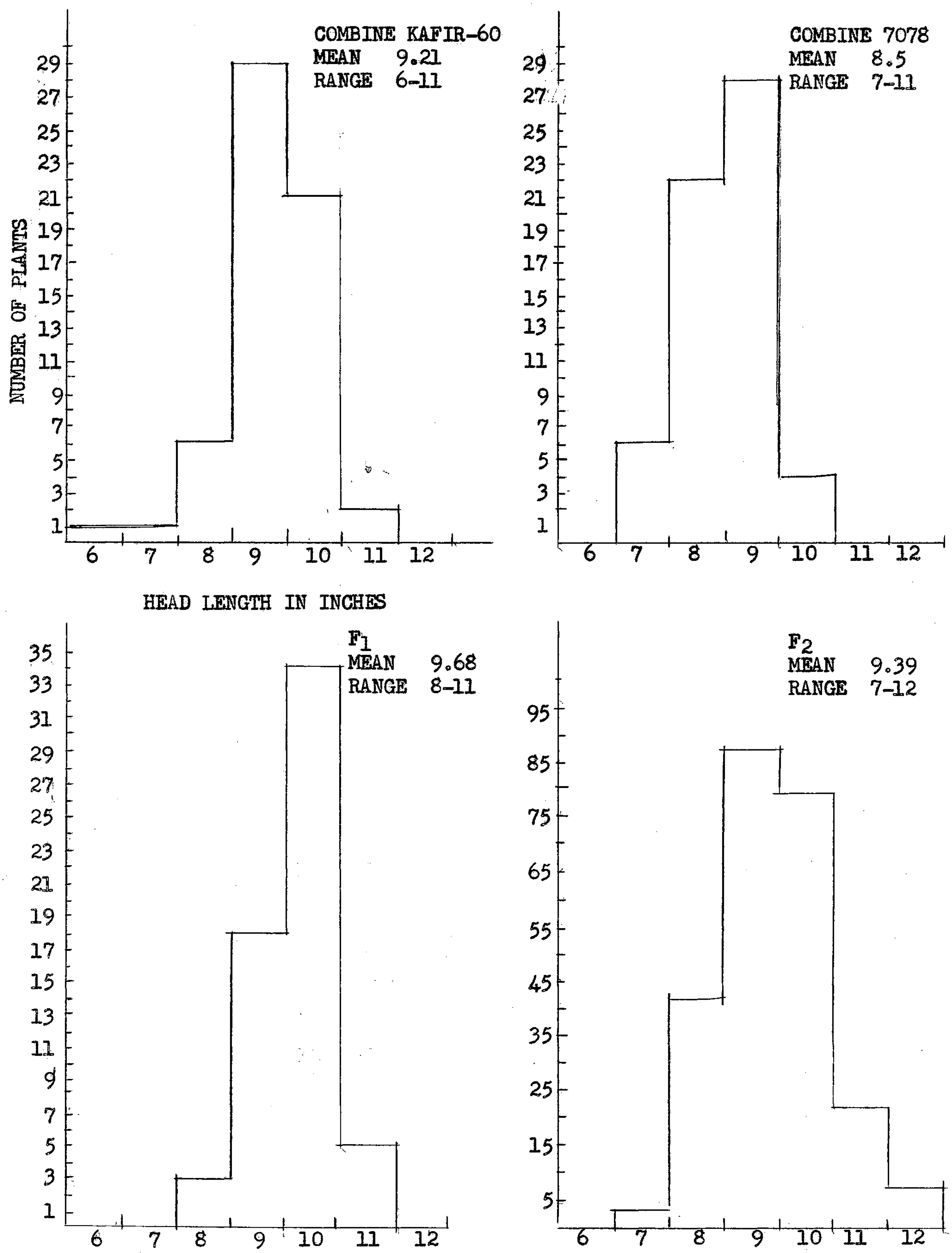


Figure 6. Frequency histograms, means and ranges of head length for the parents, F_1 and F_2 generations of cross 2, Combine kafir-60 x Combine 7078.

mean head length of the F_1 hybrid and the F_2 population exceeded the mean of the larger parent, indicating heterosis.

Table VI represents the analysis of variance of head length for cross 2. Significant differences were indicated between parents at the 5 percent level, and between the F_1 hybrid and parents at the one percent level. The mean of the F_1 hybrid exceeded the mean of the two parents by 1.23 inches.

Number of tillers per plant: Tillering was practically absent in all generations for both crosses. This character will not be included in further discussions.

Head weight: It was found that head weight and threshed grain weight were highly correlated in both the crosses. The correlation coefficients between these two variables were 0.96 and 0.95 in the two crosses. Hence the frequency distributions for head weight will follow the same pattern as the distributions of grain yield, as presented in Figures 7 and 8. The mean head weights (in grams) of parents, F_1 and F_2 of cross 1 were as follows:

Redlan	Plainsman	F_1	F_2
106.60	99.06	115.96	108.02

The above means indicate that the head weight of the F_1 hybrid was greater than the parents. The F_2 mean was also greater than the heavier parent. Heterosis was quite evident in the F_1 hybrid. The analysis of variance of head weight for cross 1 in Table VII indicated a significant difference between the F_1 and the parents at the 5 percent level.

The mean head weights (in grams) of Combine kafir-60, Combine 7078, F_1 and F_2 generations are given below:

TABLE VII

Analysis of variance of individual plant data for head weight of the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	53300.17	
Replications	3	725.17	241.7
Varieties	2	8597.20	4298.6 *
P_1 vs. P_2	1	1732.80	1732.8
F_1 vs. $P_1 + P_2$	1	6864.40	6864.4 *
Reps x Varieties (Error)	6	3675.29	612.5
Reps x (P_1 vs. P_2)	3	2293.80	764.6
Reps x (F_1 vs. $P_1 + P_2$)	3	1381.48	460.4
Within varieties	168	40302.51	239.8
P_1	56	11206.39	200.1
P_2	56	13275.59	237.0
F_1	56	15820.53	282.5
F_2	224	82542.49	368.4

TABLE VIII

Analysis of variance of individual plant data for head weight of the parents and F_1 of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	110242.07	
Replications	3	516.11	172.03
Varieties	2	58395.28	29197.64*
P_1 vs. P_2	1	1140.83	1140.83
F_1 vs. $P_1 + P_2$	1	57254.45	57254.45**
Reps x Varieties (Error)	6	2473.21	412.20
Reps x (P_1 vs. P_2)	3	261.43	87.14
Reps x (F_1 vs. $P_1 + P_2$)	3	2211.78	737.26
Within varieties	168	48857.47	290.81
P_1	56	6323.86	112.92
P_2	56	15313.46	273.41
F_1	56	27220.15	486.07
F_2	224	80699.15	360.26

* Significant at the 5 percent level.
**Significant at the 1 percent level.

Combine kafir-60	Combine 7078	F_1	F_2
89.40	99.56	130.35	104.44

Heterosis was evident in the F_1 hybrid which exceeded the greater parent by about 30 grams. Analysis of variance of head weight for cross 2 is given in Table VIII. The difference in head weight between the parents was not significant while the difference between parents and F_1 hybrid was highly significant.

The heavier heads of F_1 in cross 1 cannot be attributed to longer heads as there was no significant difference in head length. In cross 2, however, the length of the F_1 heads was significantly larger and this may be one of the factors contributing to heavier heads.

Grain yield: Sampled frequency distributions, means and ranges of grain yield for cross 1 are reported in Figure 7. The comparison of parental means showed that Redlan was higher yielding than Plainsman, but the F_1 hybrid exceeded both of the parents in grain yield. The range of the F_2 population was very wide with the mean almost equal to the larger parent. Analysis of variance of parents and F_1 of cross 1 for grain yield is given in Table IX. A significant difference was found between parents and F_1. Parents did not differ significantly.

Figure 8 contains sampled frequency distributions, means and ranges of grain yield for cross 2. There was very little difference between the means of grain yield of the two parents. The F_1 hybrid exceeded Combine 7078, the larger parent, by about twenty-five grams. This was a significant increase over the means of the parents, as indicated in the analysis of variance in Table X. The F_2 mean grain yield was also higher than the parents. Variation in the F_1 population was greater than the F_2 generation. This may have been due to the considerably

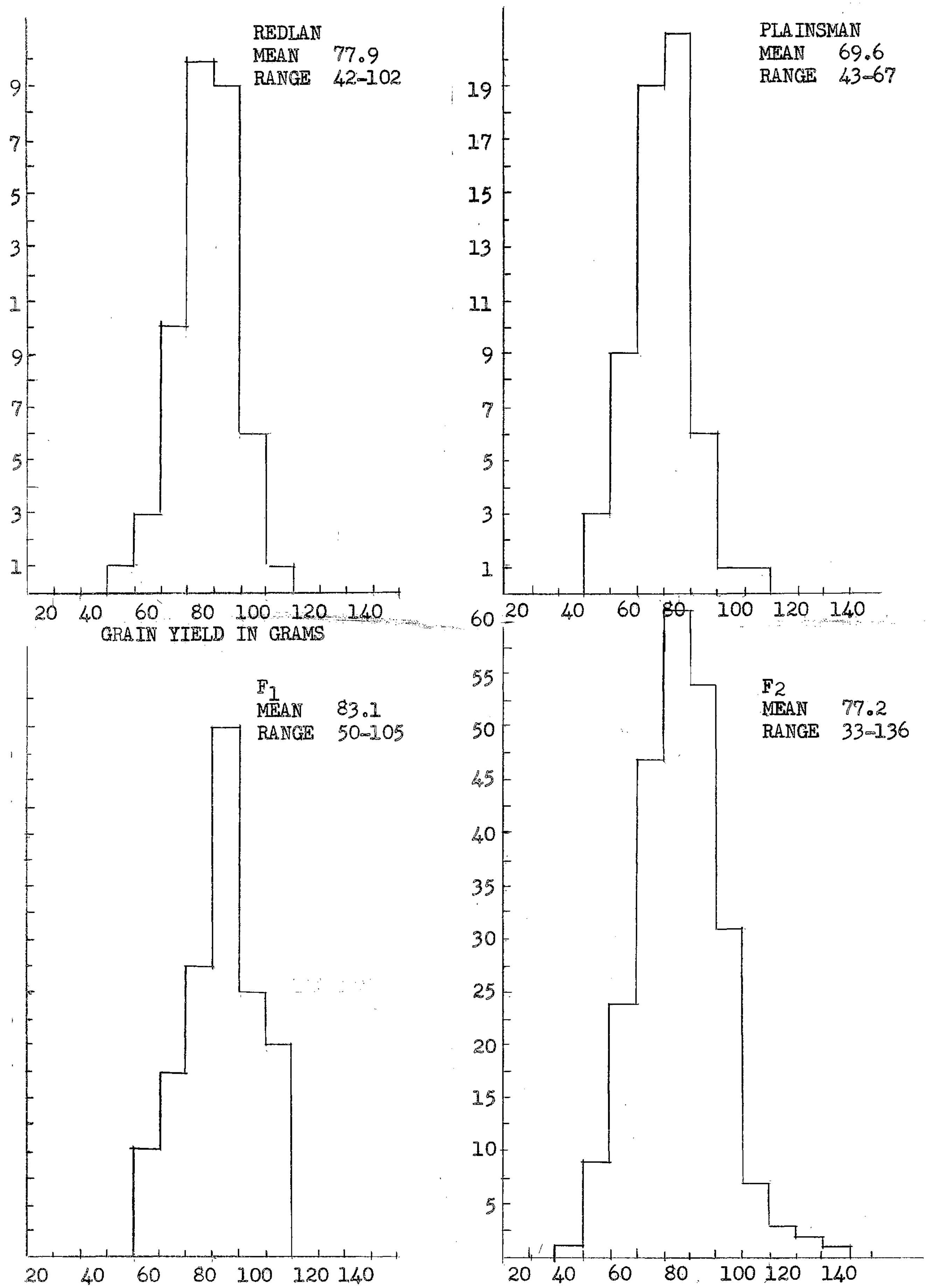


Figure 7. Frequency histograms, means and ranges of grain yield per plant for the parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman.

TABLE IX

Analysis of variance of individual plant data for grain yield of the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	34377.40	
Replications	3	173.84	57.94
Varieties	2	5570.01	2785.00*
P_1 vs. P_2	1	2041.88	2041.88
F_1 vs. $P_1 + P_2$	1	3528.10	3528.10*
Reps x Varieties (Error)	6	2202.35	367.05
Reps x (P_1 vs. P_2)	3	1342.75	447.58
Reps x (F_1 vs. $P_1 + P_2$)	3	859.60	286.53
Within varieties	168	26431.18	157.32
P_1	56	7576.26	135.29
P_2	56	8404.39	150.07
F_1	56	10450.53	186.60
F_2	224	51521.47	230.00

TABLE X

Analysis of variance of individual plant data for grain yield of the parents and F_1 of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	65445.40	
Replications	3	885.75	295.25
Varieties	2	31517.01	15758.50**
P_1 vs. P_2	1	696.01	696.01
F_1 vs. $P_1 + P_2$	1	30821.00	30821.00**
Reps x Varieties (Error)	6	1306.37	217.72
Reps x (P_1 vs. P_2)	3	253.82	84.60
Reps x (F_1 vs. $P_1 + P_2$)	3	1052.55	350.85
Within varieties	168	31736.27	188.90
P_1	56	5066.66	90.47
P_2	56	9350.26	166.96
F_1	56	17319.35	309.27
F_2	224	52411.17	233.90

* Significant at the 5 percent level.
**Significant at the 1 percent level.

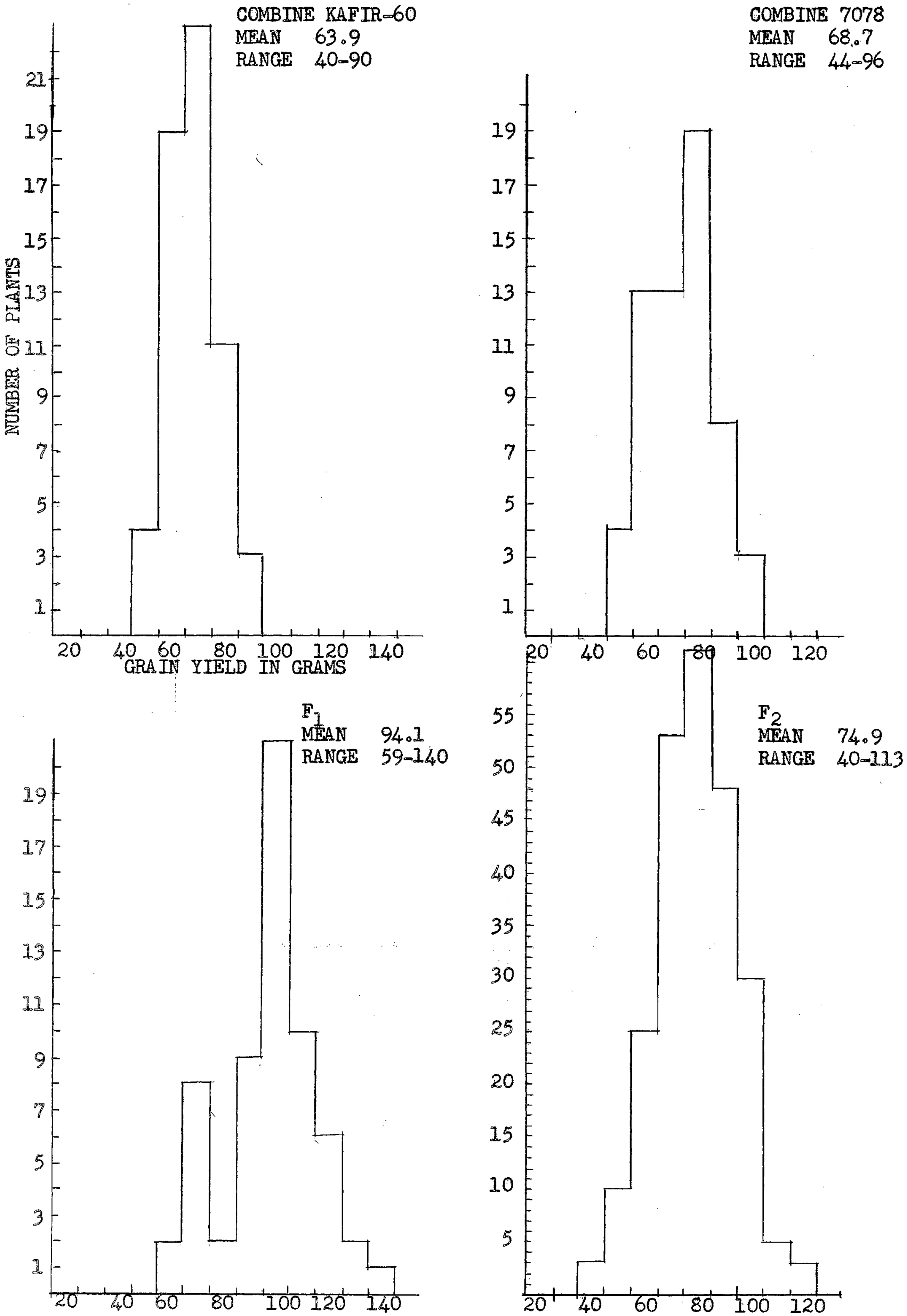


Figure 8. Frequency histograms, means and ranges of grain yield per plant for the parents, F_1 and F_2 generations of cross 2, Combine kafir-60 x Combine 7078.

higher yield of some plants which widened the range. The data on grain yield indicated that the higher weight of the hybrid heads was due to more grain yield in both crosses.

Threshing percentage: Sampled frequency distributions, means and ranges of threshing percentage for cross 1 are presented in Figure 9. There was a difference of about 2.7 percent between the mean threshing percentage of Redlan and Plainsman. The means of the F_1 and the F_2 were intermediate between the parents.

The difference between the parents was found to be significant in the analysis of variance given in Table XI. This was due to the very insignificant difference between the F_1 and the parents which increased the mean square for the comparison between parents.

Sampled frequency distributions, means and ranges of threshing percentage for cross 2 may be found in Figure 10. The means of the parents, F_1 and F_2 were very similar. Ranges of Combine 7078 and F_2 population were wide due to some individual scattered observations.

The analysis of variance of threshing percentage for cross 2 in Table XII, showed no significant differences.

Weight of 100 seeds: Sampled frequency distributions of weight of 100 seeds, their means and ranges for cross 1 are shown in Figure 11. The frequency histogram of Plainsman is skewed with the accumulation of observations towards the lighter weight side. The means of the F_1 hybrid and the F_2 population were intermediate between the two parents. Histograms of F_1 and F_2 seemed to indicate genetic control by quantitative characters. There was no effect of heterosis on seed size in cross 1. The range of the F_1 population was increased due to a plant which had very heavy seeds. A large range in the F_2 was expected due to recombinations.

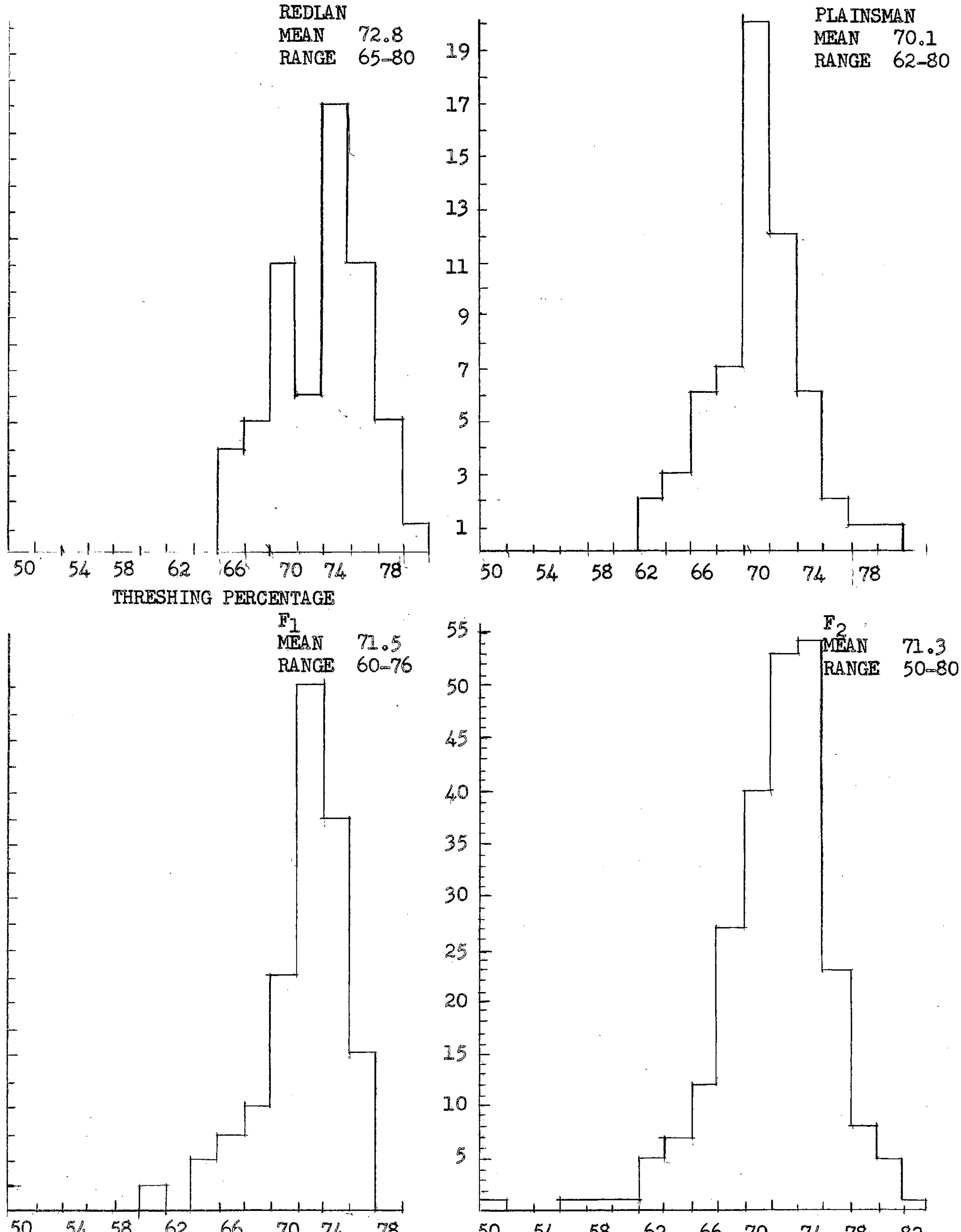


Figure 9. Frequency histograms, means and ranges of threshing percentage for the parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman.

TABLE XI

Analysis of variance of individual plant data for threshing percentage of the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	2323.82	
Replications	3	113.94	37.98
Varieties	2	216.58	18.29
P_1 vs. P_2	1	216.55	216.55*
F_1 vs. $P_1 + P_2$	1	0.03	0.03
Reps x Varieties (Error)	6	106.50	17.75
Reps x (P_1 vs. P_2)	3	75.52	25.14
Reps x (F_1 vs. $P_1 + P_2$)	3	30.99	10.33
Within varieties	168	1886.77	11.23
P_1	56	719.91	12.85
P_2	56	618.63	11.04
F_1	56	548.23	9.78
F_2	224	4274.12	19.08

TABLE XII

Analysis of variance of individual plant data for threshing percentage of the parents and F_1 of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	3257.29	
Replications	3	365.59	121.86
Varieties	2	20.33	10.16
P_1 vs. P_2	1	9.86	9.86
F_1 vs. $P_1 + P_2$	1	10.47	10.47
Reps x Varieties (Error)	6	315.87	52.64
Reps x (P_1 vs. P_2)	3	50.52	16.84
Reps x (F_1 vs. $P_1 + P_2$)	3	265.35	88.45
Within varieties	168	2555.50	15.21
P_1	56	828.53	14.79
P_2	56	819.14	14.62
F_1	56	907.83	16.21
F_2	224	4621.92	20.63

* Significant at the 5 percent level.

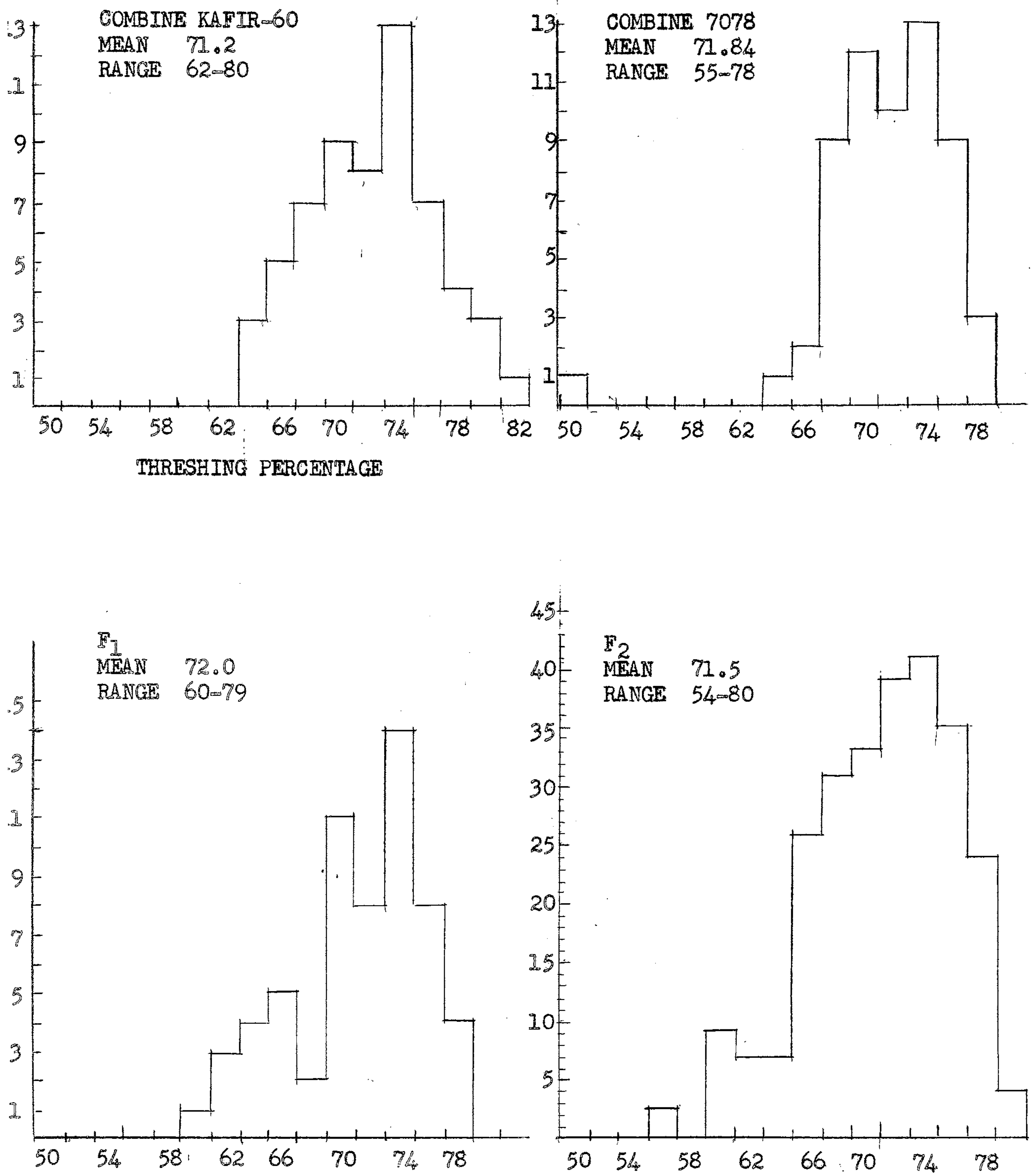


Figure 10. Frequency histograms, means and ranges of threshing percentage for the parents, F_1 and F_2 generations of cross 2, Combine kafir-60 x Combine 7078.

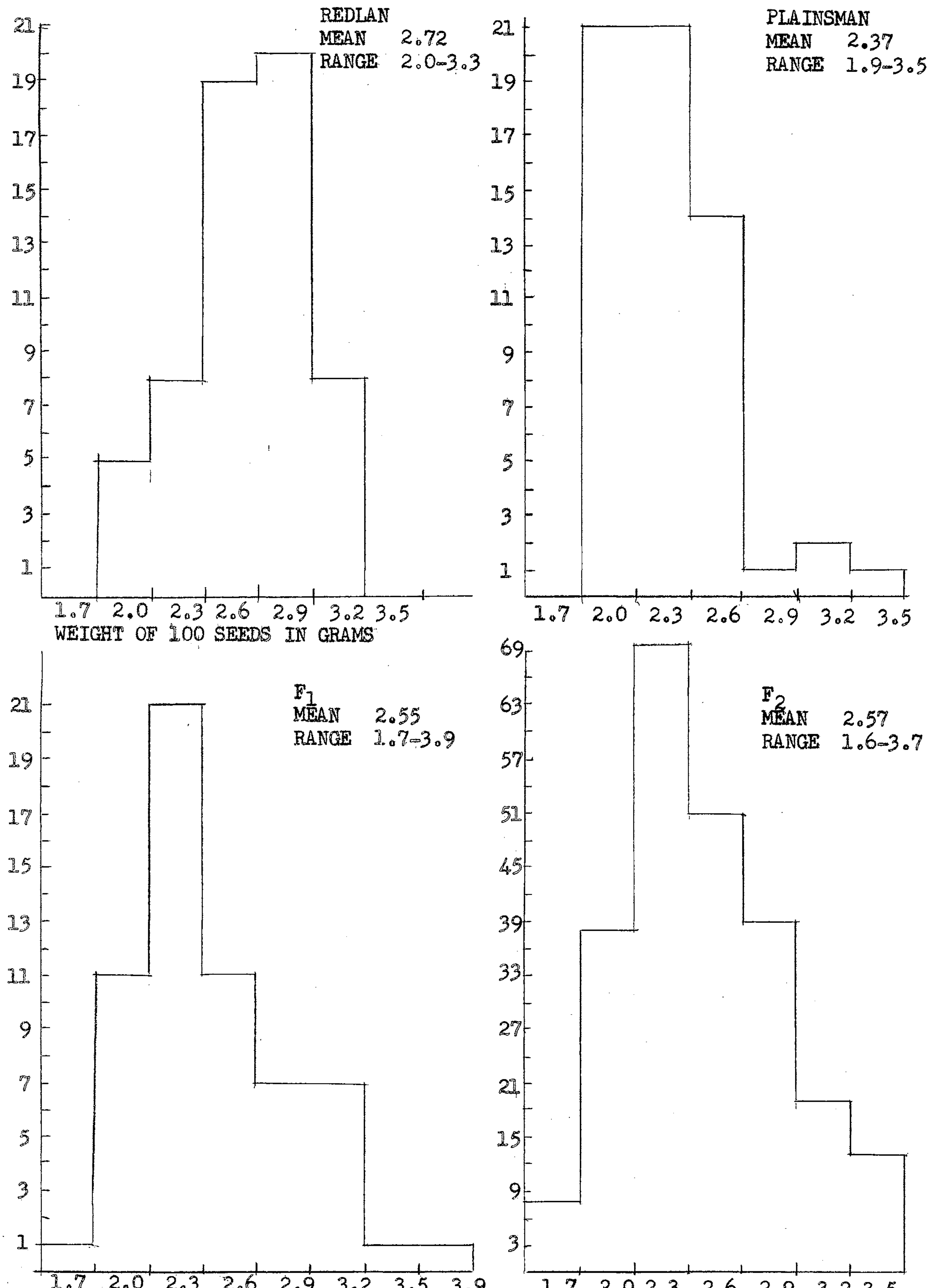


Figure 11. Frequency histograms, means and ranges of weight of 100 seeds for the parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman.

Analysis of variance of weight of 100 seeds for cross 1 is given in Table XIII. The difference between the parents was significant, indicating that Redlan seeds were heavier than those of Plainsman. There was no significant difference between the F_1 and the parents. These data on weight of 100 seeds seem to indicate that the higher yield of grain in this hybrid was not due to the heavier seeds.

Figure 12 refers to the sampled frequency distributions, means and ranges of weight of 100 seeds for cross 2. Seeds of Combine 7078 were 0.57 grams heavier than Combine kafir-60. The mean of the F_1 hybrid was greater than the mean of the two parents but did not exceed the heavier parent. The mean weight of 100 seeds of the F_2 population was intermediate between the parents with a larger range.

Analysis of variance for weight of 100 seeds for cross 2 is given in Table XIV. The difference between the seed weight of Combine kafir-60 and Combine 7078 was highly significant. Difference between the F_1 and the parents was not significant. Again the higher yield of grains of this hybrid was not due to the heavier seeds.

<u>Number of seeds per plant</u>: Sampled frequency histograms for number of seeds per plant for cross 1 are presented in Figure 13. The means of the parents differed only by 88 seeds. The mean of the hybrid was greater than the larger parent by 364 seeds. The F_2 mean was also higher than the larger parent with a wider range.

Analysis of variance for number of seeds per plant for cross 1 may be found in Table XV. A significant difference at the 5 percent level was found between the F_1 hybrid and parents.

Figure 14 will indicate the sampled frequency distributions, means, and ranges of number of seeds per plant for cross 2. Heterosis was

TABLE XIII

Analysis of variance of individual plant data for weight of 100 seeds of the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

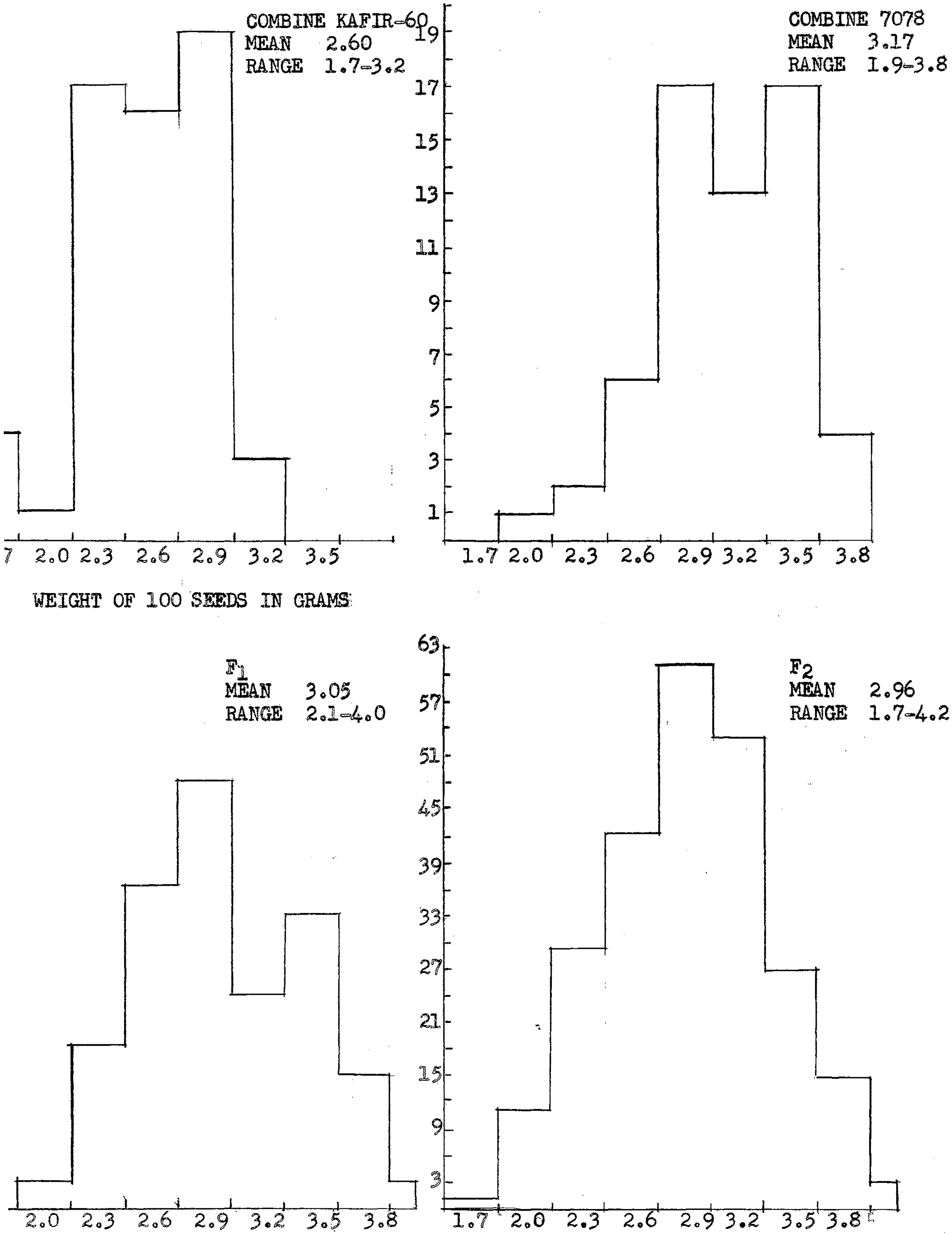
Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	29.13	
Replications	3	0.42	0.14
Varieties	2	3.81	1.90*
P_1 vs. P_2	1	3.71	3.71**
F_1 vs. $P_1 + P_2$	1	0.10	0.10
Reps x Varieties (Error)	6	1.10	0.18
Reps x (P_1 vs. P_2)	3	0.97	0.32
Reps x (F_1 vs. $P_1 + P_2$)	3	0.13	0.04
Within varieties	168	23.77	0.14
P_1	56	6.51	0.11
P_2	56	5.46	0.09
F_1	56	11.80	0.21
F_2	224	42.12	0.18

TABLE XIV

Analysis of variance of individual plant data for weight of 100 seeds of the parents and F_1 of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	38.78	
Replications	3	2.78	0.92
Varieties	2	10.61*	5.30**
P_1 vs. P_2	1	9.55*	9.55**
F_1 vs. $P_1 + P_2$	1	1.06	1.06
Reps x Varieties (Error)	6	1.18	0.19
Reps x (P_1 vs. P_2)	3	0.45	0.15
Reps x (F_1 vs. $P_1 + P_2$)	3	0.73	0.24
Within varieties	168	24.21	0.14
P_1	56	4.81	0.08
P_2	56	9.44	0.16
F_1	56	9.96	0.17
F_2	224	46.02	0.20

* Significant at the 5 percent level.
**Significant at the 1 percent level.



ire 12. Frequency histograms, means and ranges of weight of 100 seeds for the parents, F_1 and F_2 generations of cross 2, Combine kafir-60 x Combine 7078.

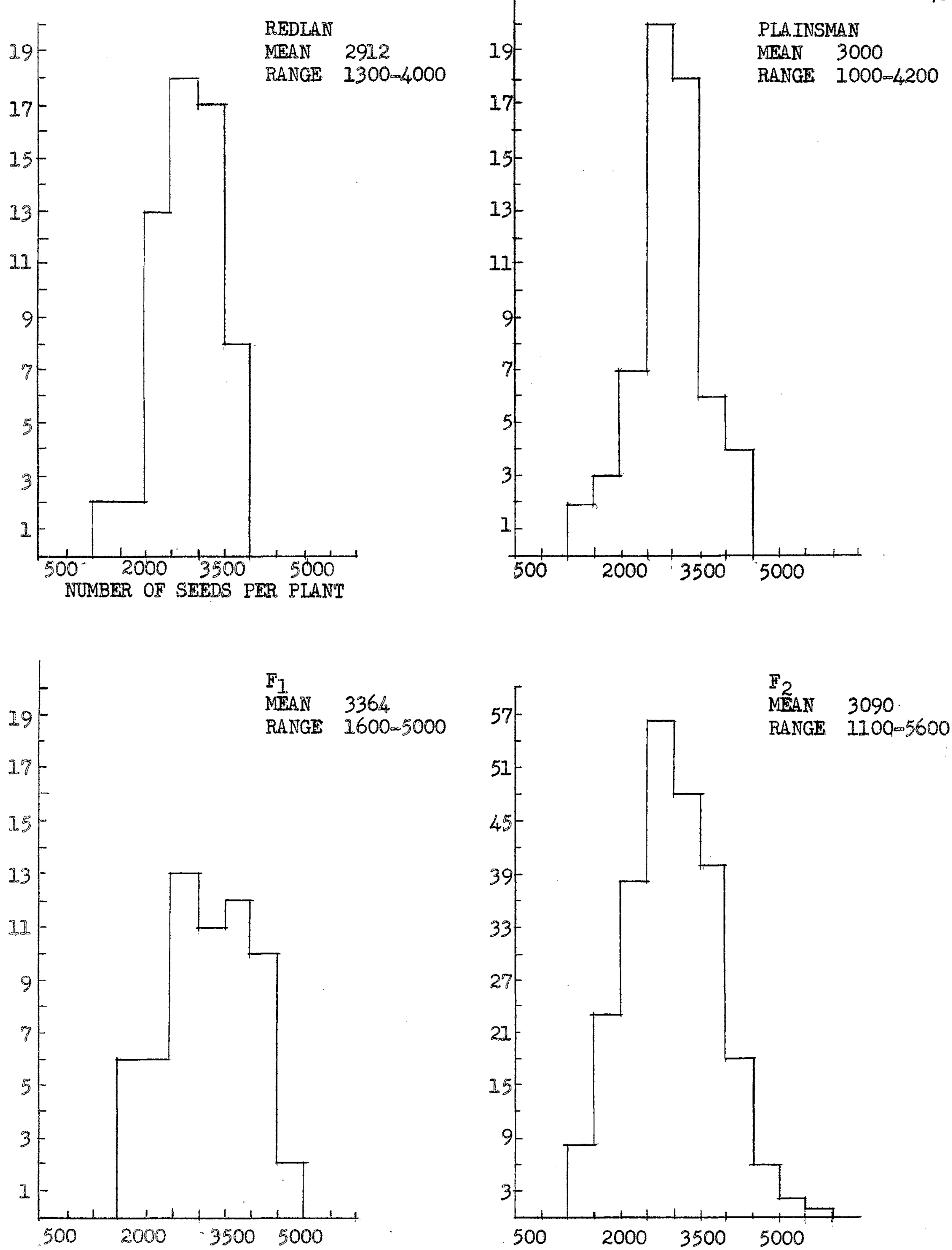


Figure 13. Frequency histograms, means and ranges of number of seeds per plant for the parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman.

TABLE XV

Analysis of variance of individual plant data for number of seeds per plant of the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	94876989.	
Replications	3	1077944.	359314.6
Varieties	2	6876675.	3438337.5
P_1 vs. P_2	1	234968.	234968.0
F_1 vs. $P_1 + P_2$	1	6641707.	6641707.0*
Reps x Varieties (Error)	6	5579208.	929868.0
Reps x (P_1 vs. P_2)	3	4192275.	1397425.0
Reps x (F_1 vs. $P_1 + P_2$)	3	1386933.	462311.0
Within varieties	168	81343157.	484185.4
P_1	56	18652654.	333083.1
P_2	56	23820849.	425372.3
F_1	56	38869650.	694100.8
F_2	224	147028701.	656378.1

TABLE XVI

Analysis of variance of individual plant data for number of seeds per plant of the parents and F_1 of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	91887991.	
Replications	3	895160.	298386.6
Varieties	2	29499864.	14749932.0
P_1 vs. P_2	1	2737630.	2737630.0*
F_1 vs. $P_1 + P_2$	1	26762234.	26762234.0*
Reps x Varieties (Error)	6	4117002.	686167.0*
Reps x (P_1 vs. P_2)	3	257122.	85707.3
Reps x (F_1 vs. $P_1 + P_2$)	3	3859880.	1286626.6
Within varieties	168	57375965.	341523.6
P_1	56	13340999.	238232.1
P_2	56	11621352.	207524.1
F_1	56	32413612.	578814.5
F_2	224	91834403.	409975.0

* Significant at the 5 percent level.

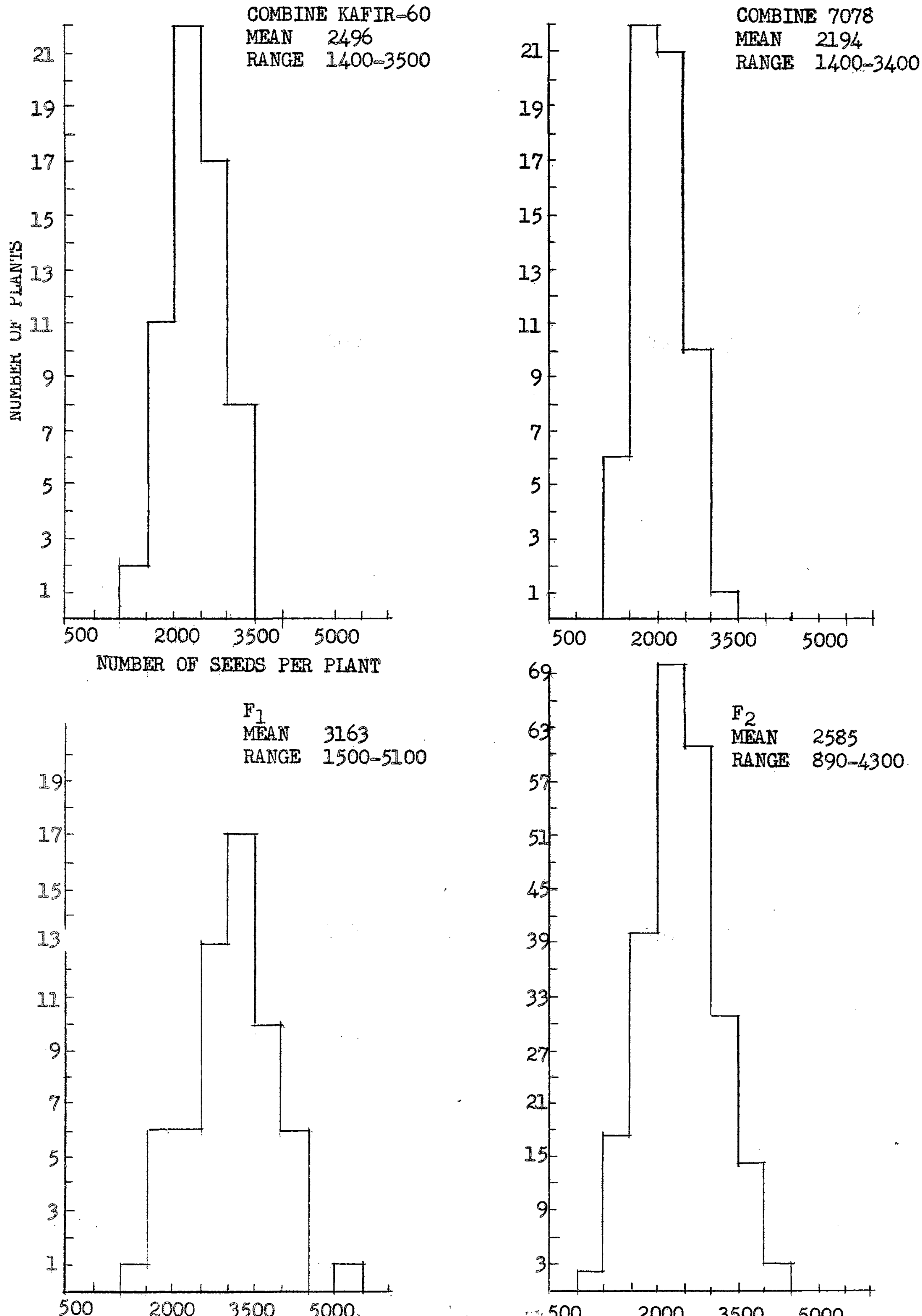


Figure 14. Frequency histograms, means and ranges of number of seeds per plant for the parents, F_1 and F_2 generations of cross 2, Combine kafir-60

evident in the hybrid, which exceeded the mean of the larger parent by 667 seeds. The range of the F_1 became wider due to a single plant which had 5100 seeds. The F_2 population had a continuous variation, was normally distributed and the mean exceeded the greater parent.

Table XVI gives the analysis of variance of number of seeds per plant for cross 2. The sub-division of error variance into its components indicated heterogeneity of variance at 5 percent level. Hence the appropriate components of error variance were used to test the significance of comparisons. This indicated significant difference between parents and between parents and F_1 at the 5 percent level. If whole error variance would have been used to test the hypothesis, then the difference between the parents would have been non-significant and difference between the parents and F_1 highly significant, giving biased results. The loss in degrees of freedom in components of variance will make its use somewhat objectionable. But it will be highly objectionable to use the heterogenous variance for testing the hypothesis.

In view of the above results, it is apparent that, increased number of seeds per head in both hybrids was a major factor contributing to the increased grain yield.

<u>Bushel weight</u>: Sampled frequency histograms of bushel weight, with means and ranges for cross 1 are given in Figure 15. The difference between the means of the parents was one pound per bushel whereas the F_1 mean was intermediate between the two parents. There was a continuous variation in the F_2 population and the mean was exactly the same as of the F_1 hybrid. These results in bushel weight were expected while considering the weight of 100 seeds.

The analysis of variance of bushel weight for cross 1 which is given in Table XVII, showed no significant differences. Generally the

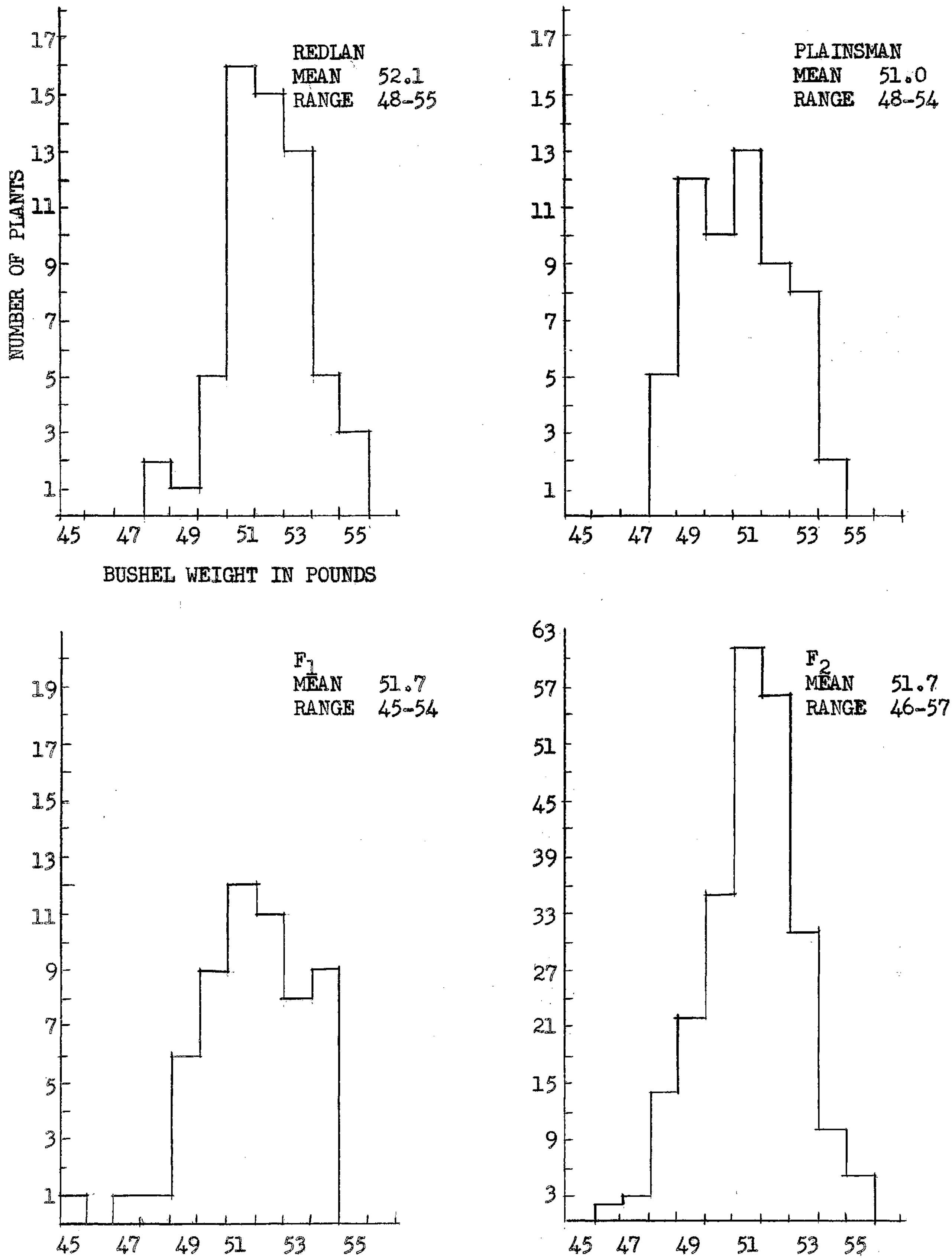


Figure 15. Frequency histograms, means and ranges of bushel weight for the parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman.

TABLE XVII

Analysis of variance of individual plant data for bushel weight of the parents and F_1 of cross 1, Redlan x Plainsman, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	858.36	
Replications	3	47.79	15.93
Varieties	2	38.33	19.16
P_1 vs. P_2	1	37.41	37.41
F_1 vs. $P_1 + P_2$	1	0.92	0.92
Reps x Varieties (Error)	6	119.81	19.96
Reps x P_1 vs. P_2	3	83.81	27.93
Reps x F_1 vs. $P_1 + P_2$	3	36.00	12.00
Within varieties	168	652.82	3.88
P_1	56	308.24	5.50
P_2	56	181.63	3.24
F_1	56	162.95	2.90
F_2	224	784.96	3.50

TABLE XVIII

Analysis of variance of individual plant data for bushel weight of the parents and F_1 of cross 2, Combine kafir-60 x Combine 7078, and F_2 variance.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	179	589.83	
Replications	3	48.76	16.25
Varieties	2	149.80	74.90**
P_1 vs. P_2	1	123.83	123.83**
F_1 vs. $P_1 + P_2$	1	25.97	25.97*
Reps x Varieties (Error)	6	20.97	3.49
Reps x (P_1 vs. P_2)	3	4.65	1.55
Reps x (F_1 vs. $P_1 + P_2$)	3	16.32	5.44
Within varieties	168	370.30	2.20
P_1	56	112.03	2.00
P_2	56	119.20	2.12
F_1	56	139.07	2.48
F_2	224	732.49	3.27

* Significant at the 5 percent level.
**Significant at the 1 percent level.

bushel weight of sorghums varies around 56 pounds. The bushel weights calculated in this test were around 50 pounds. This may have been due to the use of a micromethod for determining bushel weight as described by Swanson (38) for use on wheat samples. The available grain from single plants would not permit use of standard bushel weight apparatus. As all the bushel weights of varieties and other generations were determined by the same procedure, relative data should have been obtained.

Figure 16 represents the sampled frequency distributions, means and ranges of bushel weight for cross 2. Combine kafir-60 averaged two pounds higher in bushel weight than Combine 7078. The mean of the F_1 hybrid for bushel weight was very near to the heavier parent. The F_2 mean was intermediate between the parents and it had a greater range of variation with a continuous and normal frequency distribution.

Table XVIII gives the analysis of variance of bushel weight for cross 2. A highly significant difference was indicated between the parents and a significant difference was noted between the parents and F_1 hybrid. These differences though not evident from the data were recorded due to an unexplained small error variance.

<u>Differences of various characters in male fertile and male sterile plants of F_2 populations</u>: Reference was made to the male sterility in F_2 populations of the two crosses. It was stated that it would be of interest to know whether there were any differences in various characters of fertile and sterile plants. The means of various characters of fertile and sterile plants are presented in Table XIX. In the two crosses differences between means were found in head weight, grain yield, weight of 100 seeds, and number of seeds per plant. The differences were statistically tested by analysis of variance. Table XX gives the analysis

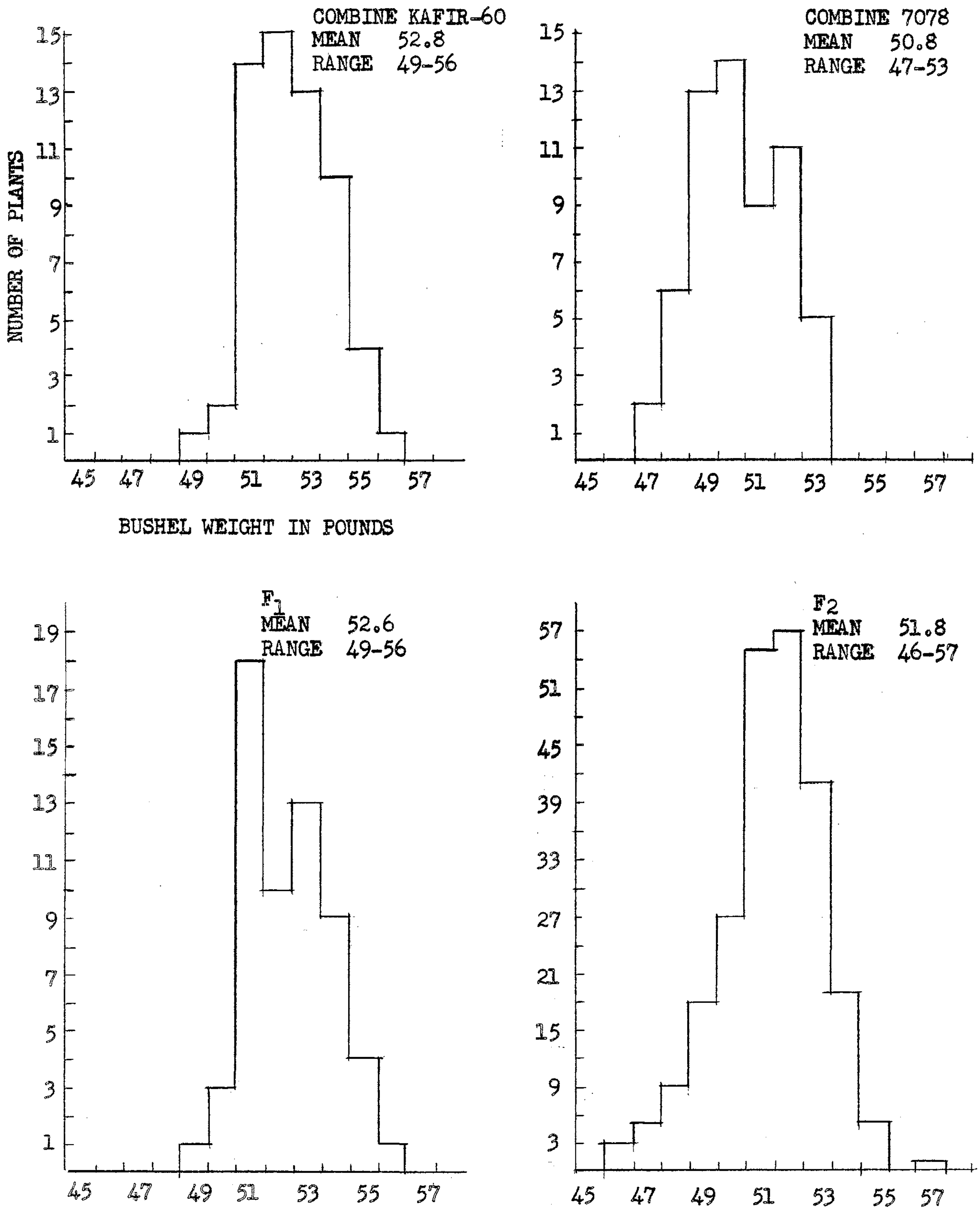


Figure 16. Frequency histograms, means and ranges of bushel weight for the parents, F_1 and F_2 generations of cross 2, Combine kafir-60 x Combine 7078.

TABLE XIX

Means of nine plant and seed characters of male fertile and male sterile plants in F_2 populations of the two sorghum crosses

	Days to First Bloom	Plant Height in ins.	Head Length in ins.	Head Weight in gms.	Grain Yield in gms.	Weight of 100 seeds in gms.	Threshing Percentage	No. of seeds/ plant	Bushel Weight in lbs.	Total No. of Plants
					Cross 1					
Male fertile	65.1	35.69	9.31	110.8	79.4	2.54	71.4	3203	51.7	179
Male sterile	65.7	35.52	9.40	99.6	70.9	2.67	71.1	2758	51.5	61
					Cross 2					
Male fertile	66.5	40.28	9.35	105.0	74.9	2.89	71.1	2645	51.8	185
Male sterile	67.6	40.89	9.52	102.4	74.6	3.18	72.7	2384	52.0	55

TABLE XX

Analysis of variance of male fertile and sterile plants in F_2 populations of the two crosses

Source of Variation	Degrees of Freedom	Mean squares				
		Head Weight Cross 1	Head Weight Cross 2	Grain Yield Cross 1	Grain Yield Cross 2	Threshing Percentage Cross 2
Total	7					
Replications	3	3862.46	1144.56	1467.89	131.97	451.03*
Fertile vs. sterile	1	5613.24	217.29	3169.36	2.73	81.87
Error	3	1011.50	1836.75	898.13	5311.81	23.15

Source of Variation	Degrees of Freedom	Weight of 100 Seeds Cross 2	Number of Seeds Per Plant Cross 1	Number of Seeds Per Plant Cross 2	Bushel Weight Cross 2
Total	7				
Replications	3	0.0338	1173126	147552	2.71
Fertile vs. sterile	1	3.7006*	8947299	2898736	1.98
Error	3	0.1090	1383731	1063610	26047.70

* Significant at the 5 percent level.

of variance of various characters for fertile and sterile plants in the F_2 populations of the two crosses. Sums of squares for mean, replications and sterility were computed on the I.B.M. 650 by abbreviated "Doolittle" program. Error sum of squares was the difference between the total and the other sum of squares. A significant difference for head weight between fertile and sterile plants was not shown. The head weight of F_2 fertile and sterile plants of cross 2 also does not differ significantly as indicated in analysis of variance Table XX.

As reported in Table XX the analysis of variance of grain yield for cross 1 and 2, respectively, does not indicate significant differences of grain yields in the fertile and sterile plants of F_2 populations. Differences in threshing percentage of fertile and sterile plants were also not significant.

Means of weight of 100 seeds in cross 2 in Table XIX, showed that the sterile plants had larger seeds than the fertile plants in the F_2 generation. The analysis of variance given in Table XX show this difference to be significant at the 5 percent level. Sterile plants in F_2 populations of both crosses had fewer seeds than the fertile plants. Though the differences in number of seeds were not found significant in the analysis of variance, these differences appeared to be sufficient to show that the larger seeds in sterile heads were due to fewer seeds per head. Reduced competition between seeds of a head and increased nutritional potential could result in larger seeds. The fewer number of seeds in sterile plants could be due to lack of complete female fertility or to incomplete fertilization as compared to the fertile heads where every flower of a spikelet has its own pollen. Bushel weight was not affected by the sterility of plants in F_2 generations and differences were not found significant.

In view of the above results it appeared that male sterility did not effect the performance of the sterile plants as a whole. Fewer seeds on male sterile plants were to some extent balanced by increased size of seeds in sterile heads, making the differences in total yield insignificant.

Protein content: Table XXI gives the means, analysis of variance and multiple range test for protein content of cross 1. Any two means underscored by the same line are not significantly different. Significant differences were found between Redlan and Plainsman, Redlan and F_1 hybrid and Redlan and F_2 generation. The mean of the F_1 hybrid was greater than the higher parent.

Analysis of variance and multiple range test for protein content of cross 2 are reported in Table XXII. The mean of the F_1 hybrid was between the two parents. The mean of Combine kafir-60 was significantly different from all other generations.

HERITABILITIES OF CHARACTERS

The heritabilities of characters as calculated by the F_2 variance method are given in Table XXIII. Heritabilities for days to first bloom, in the two crosses, were comparatively high. The heritability estimates ranged from 40.0 to 51.0 percent in cross 1 and cross 2, respectively.

Heritabilities for plant height were the highest estimates obtained when compared to other characters in the two crosses. These were 48.8 and 73.1 percent in cross 1 and 2, respectively. These estimates were in general agreement with the heritabilities of plant height calculated by many workers on various crops (4, 12, 19, 23, 41, 42). There was a considerable difference in heritabilities between the two crosses for the same character. It was due to the larger variance of the F_2 population

TABLE XXI

Analysis of variance and multiple range test of protein content for parents, F_1 and F_2 generations of cross 1, Redlan x Plainsman

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares
Total	15	4.67	
Replications	3	3.76	1.255**
Varieties	3	0.65	0.217**
Error	9	0.25	0.028

Mean protein percentage and multiple range test[1]

Redlan	Plainsman	F_1	F_2
11.931	12.266	12.835	12.452

TABLE XXII

Analysis of variance and multiple range test of protein content for parents, F_1 and F_2 generations of cross 2, Combine kafir-60 x Combine 7078

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Total	15	15.96	
Replications	3	0.02	0.073
Varieties	3	13.35	4.452**
Error	9	2.59	0.287

Mean protein percentage and multiple range test[1]

Combine kafir-60	F_1 hybrid	F_2	Combine 7078
11.430	12.679	13.529	13.763

**Significant at the 1 percent level.

[1]The means underscored by the same line are not significantly different.

TABLE XXIII

Heritabilities of nine agronomic characters in two crosses of grain sorghum as calculated by F_2 variance method

	Cross 1 (Redlan x Plainsman)	Cross 2 (Combine kafir-60 x Combine 7078)
1. Days to First Bloom	40.0	51.0
2. Plant Height	48.8	73.1
3. Head Length	23.2	40.5
4. Head Weight	34.8	19.2
5. Grain Yield	31.6	19.2
6. Threshing Percentage	41.1	26.2
7. Weight of 100 Seeds	25.0	29.2
8. Number of Seeds Per Plant	26.2	16.6
9. Bushel Weight	-10.8	32.7

in cross 2 whereas the environmental variance remained about the same in both crosses. Individual plant selection in the F_2 populations should be effective for these two characters.

Heritability estimates of head length in cross 1 and cross 2 were 23.2 and 40.5 percent, respectively. This was a sharp reduction in values from plant height to head length, and it was due to the smaller differences between the F_2 phenotypic variance and P_1, P_2, and F_1 environmental variance. The differences between the means of the parents were slight and little segregation should be expected in F_2. This might have made the difference between the phenotypic variance and environmental variance smaller.

Head weight was relatively more heritable in cross 1 than in cross 2. Estimates obtained varied from 34.8 percent in cross 1 to 19.2 percent in cross 2. Due to the nature of the calculations high heritabilities are due to a large F_2 phenotypic variance, or a reduced environmental variance. In these two crosses the F_2 phenotypic variance was similar, while a reduction in the environmental variance in cross 1 resulted in an increase in the percent heritability. Heritabilities for grain yield were similar to head weight in both crosses. This similarity was probably due to a close association of these two characters. It appears that selection in F_2 for head weight or grain yield would be only moderately effective. This conforms to results obtained with other crops.

The estimate of heritability for threshing percentage was fairly high in cross 1 while it was relatively low in cross 2. The estimates ranged from 41.1 to 26.2 percent in the two crosses. Threshing percentage was one of the most heritable characters in cross 1, being exceeded only by plant height. Selection in the F_2 for threshing percentage would be quite effective in some crosses, but less effective in others.

Heritabilities for weight of 100 seeds were 25.0 percent in cross 1 and 29.2 percent in cross 2. There was less difference between these two estimates for the two crosses than for any other character in the study.

Number of seeds per plant for cross 1 was 26.2 percent and for cross 2 was 16.6 percent heritable. Increased phenotypic variance calculated from the F_2 population in cross 1 resulted in a comparatively higher heritability estimate for this character. Selection in F_2 for seed weight and for number of seeds per plant would be only moderately effective.

The estimate of heritability for bushel weight in cross 1 was negative. This was due to an exceptionally large environmental variance which exceeded the F_2 phenotypic variance. The resulting negative value may be considered a poor estimate of zero heritability. Bushel weight in cross 2 was 32.7 percent heritable. Apparently, selection could be moderately effective in some F_2 populations, but would be a random sample in a population like cross 1.

The F_2 variance method which has been used for calculating estimates of heritability is subjected to some limitations. It does not separate the variances due to dominance deviations and epistasis. Heritability calculated by this method is a ratio between the difference of F_2 phenotypic variance and environmental variance over F_2 phenotypic variance. An overestimation is expected due to the inclusion of dominance deviations and epistasis variances in the genotypic variance. The larger F_2 populations might have also affected the F_2 variance method since their size was four times that of the parents or F_1 hybrid. This larger population might be expected to include more variation due to environmental and other factors.

CORRELATION OF CHARACTERS

Simple correlation coefficients of various characters were calculated according to Snedecor (31) by using data from the F_2 populations of the two crosses. These coefficients are presented in Table XXIV. It was interesting to note that most of the correlation coefficients in the two crosses were very similar.

A very high positive correlation was found between head weight and grain yield (0.9), between head weight and number of seeds per plant (0.7), and between grain yield and number of seeds per plant (0.7). This indicated that plants with heavier heads had more grain yield and more seeds per plant. Days to first bloom was positively correlated with bushel weight in cross 1 and with weight of 100 seeds in cross 2. A highly significant negative correlation was found between days to first bloom and number of seeds per plant in cross 2. This suggests that early blooming plants will have more seeds with a decrease in bushel weight.

A highly significant and positive correlation was obtained between plant height and head length in both crosses. Plant height was also positively correlated with head weight and with grain yield. Therefore, it appears that the taller plants will have longer heads accompanied by high grain yield.

Head length was positively and significantly correlated with head weight, grain yield and number of seeds per plant in both crosses, and with bushel weight in cross 2, at the 5 percent level. This seems to indicate that selection for head length would be effective in improving grain yield.

TABLE XXIV

Simple correlation coefficients of nine agronomic characters in two crosses of grain sorghums calculated from F_2 data

	Head Length	Head Weight	Grain Yield	Weight of 100 Seeds	Threshing Percent	Number of seeds/plant	Bushel Weight
Days to first bloom		-0.051	-0.047	0.112	-0.055	-0.095	0.193**
		-0.026	0.021	0.348**	0.100	-0.231**	0.118
Plant height	0.413**	0.192**	0.202**				
	0.295**	0.123	0.186**				
Head length		0.405**	0.376**	-0.031		0.311**	-0.033
		0.410**	0.346**	0.084		0.227**	0.132**
Head weight			0.962**	-0.123	0.192**	0.768**	0.059
			0.959**	0.051	0.261**	0.738**	0.177**
Grain yield				-0.128**	0.444**	0.783**	0.107
				-0.001	0.513**	0.760**	0.220**
Weight of 100 seeds					-0.108	-0.690**	0.329**
					-0.028	-0.589**	0.351**
Number of seeds/plant							-0.161*
							-0.070

The upper coefficients of each pair refer to cross 1 and the lower to cross 2.

* Significant at the 5 percent level.
**Significant at the 1 percent level.

Correlation coefficients of head weight and threshing percentage showed that the heavier heads will thresh better. In cross 2 head weight was positively correlated with bushel weight.

Grain yield was negatively correlated with weight of 100 seeds, positively correlated with threshing percentage, and with number of seeds per plant in both crosses and with bushel weight in cross 2. Plants with high grain yield will, therefore, have small size seeds, with an increase in number of seeds. In cross 2 high grain yield will also be accompanied by a gain in bushel weight.

Significantly high and negative correlations were noted between weight of 100 seeds and number of seeds per plant in both crosses. Bushel weight was positively correlated with weight of 100 seeds in both crosses. It seems logical that plants with larger seeds will have less seeds. Positive correlation between weight of 100 seeds and bushel weight should not always be expected.

A negative and significant correlation was found between number of seeds per plant and bushel weight in cross 1.

SUMMARY AND CONCLUSIONS

A study of quantitative characters in two crosses of grain sorghum was undertaken at Perkins Agronomy Research Station during the summer of 1959. Ten quantitative characters studied were: (1) Days to first bloom; (2) Plant height; (3) Head length; (4) Number of tillers; (5) Head weight; (6) Grain yield; (7) Threshing percentage; (8) Weight of 100 seeds; (9) Number of seeds per plant; and (10) Bushel weight. The parents, Redlan x Plainsman (cross 1), and Combine kafir-60 x Combine 7078 (cross 2), their F_1 hybrids and F_2 generations were grown in a randomized complete block design. Sixty individual plants equally spaced at eighteen inches were studied from the parents and F_1 populations and 240 plants from the respective F_2 generations. Analyses of variance, estimates of heritability, and simple correlation coefficients were calculated by appropriate computations, (42, 41, 31). Protein content of all generations was analyzed. Male sterility in F_2 populations was observed and differences of various characters in male fertile and male sterile portions of these populations were examined.

All the characters indicated multiple factor inheritance by normal frequency distributions, with a partial dominance of tallness over shortness and larger seed size over smaller seed size in cross 2.

Male sterility was controlled by a single pair of factors in both crosses, where the gene for male fertility was dominant over its allele. A 3:1 ratio of male fertile and male sterile plants was obtained in F_2 populations.

In cross 1, heterosis of the F_1 hybrid was evident for the following characters: (1) Days to first bloom; (2) head length; (3) head weight; (4) Grain yield; (5) Number of seeds per plant; and (6) Protein content.

In cross 2 heterosis was evident in all the characters studied except protein content. Increased gain yield in the first generation hybrids was mainly due to increased seed number per plant.

The means of various characters of male fertile and male sterile plants in F_2 populations indicated that the performance of the male sterile plants was unaffected by sterility. In sterile heads seed number was reduced but this was balanced by an increase in seed size.

Plant height was highly heritable in both crosses. The estimates of heritability for this character were 48.8 and 73.1 percent in cross 1 and 2, respectively. Heritabilities of other characters ranged from -10.8 percent for bushel weight in cross 1 to 51.0 percent for days to first bloom in cross 2. It was concluded that individual plant selection in the F_2 populations should be effective for plant height and days to first bloom and moderately effective for head weight, grain yield, threshing percentage and weight of 100 seeds.

Correlation coefficients indicated a very high positive association between head weight and grain yield in both crosses ($r = 0.9$). Selection for heavier heads will, therefore, be accompanied by increased grain yield. Grain yield and number of seeds per plant were also highly and positively correlated, ($r = 0.7$), in both crosses. Significant positive associations were obtained in the following characters:

Days to first bloom and weight of 100 seeds in cross 2

____ and bushel weight in cross 1

Plant height and head length in crosses 1 and 2

_____ and grain yield in crosses 1 and 2

Head length and head weight in crosses 1 and 2

_____ and grain yield in crosses 1 and 2

_____ and number of seeds per plant in crosses 1 and 2

_____ and bushel weight in cross 2

Head weight and grain yield in crosses 1 and 2

_____ and threshing percentage in crosses 1 and 2

_____ and number of seeds per plant in crosses 1 and 2

_____ and bushel weight in cross 2

Grain yield and threshing percentage in crosses 1 and 2

_____ and number of seeds per plant in crosses 1 and 2

_____ and bushel weight in cross 2

Weight of 100 seeds and bushel weight in crosses 1 and 2

Significant negative correlations were indicated, between days to first bloom and number of seeds per plant in cross 2, between grain yield and weight of 100 seeds in cross 1, between weight of 100 seeds and number of seeds per plant in both crosses and between number of seeds per plant and bushel weight in cross 1.

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