HERITABILITIES AND INTERRELATIONSHIPS OF SPIKE SIZE AND OTHER TRAITS IN TWO WINTER WHEAT CROSSES (*TRITICUM AESTIVUM* L. EM THELL)

By

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CHAPTER I

INTRODUCTION

As world population continues to grow, the increasing demands must be met in the area of food production. Wheat is the major cereal of the world and improvement in the productivity of this crop has worldwide ramifications. High levels of production depend on many factors, among which genetic improvement is vitally important.

Traditional methods of breeding have successfully contributed to higher wheat yields in the past. Readily available genetic variability has been exploited by breeders to improve agronomic characters and remedy specific problems. As the more easily remedied problems are corrected, further increases in yield become more challenging and will require the employment of new techniques to increase the genetic potential for high yields.

The plant architecture approach to plant breeding offers a possibility of improving yield *per se* over existing systems of breeding. In this system the breeder selects for improved values of yield-related traits rather than yield itself. Spike size is one of the principal components of grain yield in wheat and is part of the plant architecture project at the Oklahoma Agricultural Experiment Station.

The objectives of this study were: a) to study the heritability estimates and interrelationships of traits dealing with spike size as well as other traits in two F_2 populations of winter wheat, and b) to determine which measure of spike size is most useful to the breeder. Heritability estimates and interrelationships were determined for the following eight traits: plant height, plant tiller number, spike length, spikelets per spike, kernels per spike, kernels per spikelet, kernel weight, and plant grain yield.

CHAPTER II

REVIEW OF THE LITERATURE

A number of different breeding schemes have been put forth as alternative ways to increase yield potential in wheat. Donald (7) presented the ideotype concept of increasing grain yield as an alternative to traditional breeding methods. He noted that past breeding efforts to increase grain yield centered either on the elimination of specific defects such as susceptibility to disease, insects, lodging, and shattering, or on the selection of grain yield *per se* in genetically variable populations derived from crosses involving parents with high yield potential. Under the ideotype approach to breeding, yield-related traits are identified and selected and ultimately combined into an idealized plant type which would maximize yield potential in a given environment. In an attempt to define an ideal plant type which would maximize the yield potential of hard red winter wheat in the Southern Great Plains of the United States, Smith (31) presented a plant architecture model. An optimum level of expression for each trait in the model was postulated giving consideration to the available genetic diversity for each trait. Under the suggested breeding scheme, selection would be directed toward the genetic modification of yield-related traits rather than grain yield itself.

Grafius (11) reported that grain yield in oats is the product of three major yield components: number of panicles per unit area, the average number of kernels per panicle, and the average kernel weight. He demonstrated theoretically that it should be possible to increase grain yield by increasing one component while holding the others constant. This concept can be extended to wheat. If appropriate units are used and the components are measured without error, grain yield can be considered as the product of tiller number, average number of kernels per spike, and average kernel weight. Selection based on yield components might be more effective in increasing yield than selection based on yield itself. This type of selection would be most effective if the components were more highly heritable than grain yield itself, genetically independent, and not physiologically associated.

In a ten-parent diallel cross (excluding reciprocals) of winter wheat, Kronstad and Foote (21) obtained the following narrow-sense heritability estimates: grain yield per plant (0.259), spikes per plant (0.401), kernel weight (0.472), kernels per spikelet (0.478), spikelets per spike (0.607), and plant height (0.829). These results indicated that yield components may respond to selection more so than grain yield itself. They (21) suggested that the components compete for the same total amount of metabolic substrate, and that conditions favoring the development of one component could result in an adverse effect on the other components. In such a case, compromises in the desired levels of expression of each component would be required to maximize grain yield.

In a cross between 'Seu Seun 27' and 'Blue Jacket' winter wheats, Johnson et al. (15) found broad- and narrow-sense heritability estimates for spike length and kernel weight to be higher than those for grain yield. Broad-sense heritabilities for the number of rachis internodes per spike and the number of spikes per plant were larger than that of grain yield, but narrow-sense heritability estimates for these traits were lower than that of grain yield. In a seven-parent diallel winter wheat cross, Fonseca and Patterson (9) found yield components consistently more highly heritable than grain yield. Narrow-sense heritability estimates from their F_2 hill-plot data were: grain yield (0.28 ± .15), kernel weight (0.44 ± .11), spikes/930 cm^2 (0.62 ± .07), and kernels per spike (0.79 ± .12).

Gill et al. (10) working with a partial diallel involving Indian and exotic wheat germplasm, reported narrow-sense heritability estimates as follows: tiller number (0.12), spike length (0.337), ten-grain weight (0.385), plant height (0.538) and kernels per spike (0.77). Additive genetic variance was found to be much larger than dominance genetic or environmental variance for kernels per spike, and it was suggested that variability for this trait could be exploited by simple breeding procedures. In contrast, Ketata et al. (17) as well as Sidwell et al. (30) found extremely low narrow-sense heritability estimates for kernels per spike. Of the spike characters analyzed by Sidwell et al. (30) only spikelets per spike had a higher narrow-sense heritability than grain yield.

In two different populations Ketata et al. (18) detected epistasis for heading date, kernels per spikelet, and grain yield. Epistasis was detected for kernel weight in one of the two populations, while no epistasis was found in either population for plant height, tiller number, spikelets per spike, or kernels per spike. Additive genetic variance was predominant for spikelets per spike and kernels per spike, although some dominance genetic variance in a negative direction was found for kernels per spike. In the population in which no epistasis was detected for kernel weight, genetic variance for this trait was solely additive. Sidwell et al. (30) found genetic variance for kernel weight to be almost entirely due to additive gene action.

Heritability estimates may be useful for predicting the response of a character to direct selection, but correlations between characters must also be considered. Johnson et al. (15) found significant phenotypic and genotypic correlations to be positive in sign and intermediate in magnitude between plant height and kernel weight in the progeny of a cross between the two winter wheats Seu Seun 27 and Blue Jacket. In a comparative study of four winter wheat lines and cultivars differing in plant height, Johnson et al. (16) reported that the short-statured line 'C.I.13678' owed its yield superiority to a larger number of kernels per spike than the other three cultivars. The larger number of kernels per spike in C.I.13678 was associated with longer spikes, more spikelets per spike, and more kernels per spikelet. However, this line had lower kernel weight, and fewer tillers than the other cultivars tested. The deficiency in the two latter traits was more than compensated, however, by the magnitude and stability of kernels per spike.

Fonseca and Patterson (9) reported simple correlation coefficients among plant characters from different generations in a seven-parent diallel winter wheat cross. Grain yield had a high positive correlation with spikes per plot in the F_1 generation and in the F_1, F_2, and parents combined data set. A large negative correlation was found between kernels per spike and spikes per plot in the F_1 and parents combined. Statistically significant correlations between plant height and yield components were positive and low in magnitude. In a backcrossing program which involved transferring high kernel weight from 'Selkirk' to

'Thatcher' spring wheat, Knott and Talukdar (20) found a significant negative correlation of intermediate magnitude between kernel weight and kernels per plot, while a large negative correlation was found between kernels per spike and spikes per plot. The increase in kernel weight resulted in a reduction of either kernels per spike or spikes per plot, or both. However, the reduction of these characters was not sufficient to counteract the gain made by increased kernel weight. Hsu and Walton (14) reported simple correlations among yield components and yield in the F_1, F_2, and backcross progenies from a five-parent diallel spring wheat cross. Two-way correlations of seven traits with grain yield per plant were as follows: kernels per spike (0.79), spikes per plant (0.74), spikelets per spike (0.73), spike length (0.72), and kernel weight (nonsignificant). The correlation coefficient between kernels per spike and spike length was 0.69, while that between kernels per spike and spikelets per spike was 0.63. A negative correlation of (-0.39) was found between kernel weight and number of spikes per plant.

McNeal et al. (22) selected for yield and yield components in a spring wheat cross in the F_2 and subsequent generations through the F_8. Grain yield was increased significantly over the midparent by selection either for kernels per spike or kernel weight. Direct selection for grain yield per plant produced no response, while selection for spikes per plant produced a fluctuating response resulting in a reduction in this trait by the F_8 generation. Direct selection for kernel weight was effective in increasing this trait well above the midparent value. Direct selection for kernels per spike resulted in a large increase for this trait by the F_4 generation with no further increase in subsequent generations. Gene combinations for this trait appeared to be fixed by the F_3 generation, and it was suggested that the parents may have differed by relatively few genes for kernels per spike. Interestingly, direct selection for kernels per spike resulted in an increase in kernel weight. Selection for spikelets per spike resulted in a sizable increase in kernels per spike in the F_8 generation. It was concluded that single character selection can improve yield, but long range yield improvement would likely require improvement of more than one yield component.

Thorne (35) reported that large increases in one yield component are usually accompanied by decreases in other components. Smith (31) observed that the Turkey-type wheats grown in the Southern Great Plains generally have a high tillering ability and a rather low number of kernels per spike. Negative associations between yield components have been found by a number of investigators cited previously in this chapter (9, 14, 16, 20). According to Adams (1) such results most likely stem from sequentially developing components of yield sharing a common metabolic pool. This theory maintains that yield components are genetically independent but developmentally associated. From this it would be expected that genotypes characterized by high expression of one component would have relatively lower expressions in the remaining components. Grafius and Thomas (12) suggested that determination of remote traits in a developmental sequence is largely dependent on the determination of initial traits in the sequence, and consequently, genetic control of the end traits is limited. Thomas et al. (34) found that the heritability of kernel weight, a trait often having relatively high heritability, was driven to zero by removal of the correlated effects of the other yield components.

The effect of interplant competition on yield component expression was apparent in an early study by Kiesselback and Sprague (19). When Turkey wheat was sown at rates below normal the number of spikes per plant, the number of spikelets per spike, and the number of kernels per spike increased. When planting dates were later than normal the number of spikes per unit area decreased, while the number of spikelets per spike and kernels per spike increased suggesting a compensatory relationship among these components. Puckridge and Donald (26) observed with wheat that the number of spikes per plant and the number of spikelets per spike decreased with increasing plant density. At low plant densities production of tillers continued long after tillering had ceased in more densely populated stands. Both kernels per spike and kernels per spikelet decreased with increased plant density, except from the lowest plant density in which the traits had lower than expected values. The exception was interpreted to reflect extreme intertiller competition within profusely tillered plants or could have arisen due to the presence of very small spikes on the late tillers.

Puckridge (25) reported that the total number of spikelets per spike remained constant in single culm plants regardless of plant spacing, but the number of sterile spikelets was greater in dense populations. This decrease in fertility was thought to result from increased competition for assimilates among the developing spikelets at high culm density. The total number of spikelets per spike was affected at both high and low plant densities by the application of nitrogen fertilizer.

Thorne (35) noted that the demand for assimilate by the sink affects production and flow of assimilate from the source. Donald (7) suggested that if the proposition of sink limitation to grain yield was accepted, then a larger number of florets per spike would be required to increase yield potential. He related sink limitation to a survival mechanism of the plant. Accordingly, the number of florets (sinks) produced varies with environmental conditions during plant ontogeny, so that the number of florets that develop are within the photosynthetic capacity of the plant. Bingham (5) reported that the source and sink interact in field situations so that their relative importance varies, and neither are fully exploited for grain production.

Rawson (27) noted in a comparative study of spike size in spring wheat cultivars that those with the highest numbers of spikelets per spike were always associated with a longer period from seedling emergence to terminal spikelet formation. Generalizing on this, Bingham (5) suggested that spike size is dependent upon the time of onset and duration of successive phases of development, which are tied to photoperiod and vernalization responses. Bingham (5) proposed that an early increase in the size of the growing point relative to culm length would enable the developing spike to better compete with the elongating culm. He concluded that since late florets are capable of setting grain in experimental conditions, their failure to develop under field conditions is probably due to insufficient time for full development or to a shortage of assimilates. Schmidt (28), however, mentioned that Turkey-type wheats may carry an inhibitor of spike fertility. This possibility is also suggested by the work of Evans et al. (8) which indicated that hormonal inhibition of spike fertility may occur. Evidence has been presented by Suetka (33) that much higher levels of spike fertility may be achieved through the use of the branching spike character found in some wheats.

Johnson et al. (16) reported that a high number of kernels per spike may be of value in stabilizing wheat yield, while Donald (7) stressed the importance of spike size in breeding for high yield potential in wheat. Referring to the components of spike size, Bingham (5) reported that no special advantage would be gained by assigning priority to spikelet number per spike over kernel number per spikelet, or the converse, except that kernels per spikelet is the most efficient in use of assimilate. Borojevic (6) noted, however, that the photosynthetic area of the spike plays an important role in the grain filling process, and consequently, mid-dense spikes having many spikelets with large awns and glumes would be desirable.

CHAPTER III

MATERIALS AND METHODS

Materials

Two F_2 populations originating from crosses made in the greenhouse were studied during the 1977-78 crop season. The two populations involved a common unadapted germplasm line, 'Fundulea 23-71', which will be hereafter referred to as 'F 23-71'. Population 1 consisted of: a) 320 F_2 plants from the cross 'Caprock'/F 23-71, b) the two homozygous parents Caprock and F 23-71, and c) the two checks '77ST6338A' and 'Newton'. Population 2 consisted of: a) 320 F_2 plants from the cross 'Tam W-101'/F 23-71, b) the two homozygous parents Tam W-101 and F 23-71, and c) the two checks 77ST6338A and Newton.

F 23-71 was developed at the Fundulea Station in Romania from the cross 'Neuzucht'/'F 362-62'. Neuzucht was a German breeding line, and F 362-62 a Romanian breeding line. F 23-71 is a winter wheat characterized by large spikes, medium sized kernels, tall stature, and late maturity. It is the best genotype so far evaluated in Oklahoma regarding number of spikelets per spike (32).

Caprock is a hard red winter wheat that was released by the Texas Agricultural Experiment Station in 1969. Caprock was selected from the cross 'Sinvalocho'/'Wichita'/2/'Hope'/'Cheyenne'/Wichita/4/Seu Seun 27. Caprock, a sister strain of 'Sturdy', is characterized by short straw, medium sized kernels, early maturity, and good milling and baking quality (4).

Tam W-101 is a hard red winter wheat that was released by the Texas Agricultural Experiment Station in 1971. Selected from the cross 'Norin 16'/3/'Nebraska 60'//'Mediterranean'/Hope/4/'Bison', Tam W-101 is characterized by short straw, relatively large kernels, medium maturity, and good yield potential (24).

The two checks, 77ST6338A and Newton, were used in both populations. 77ST6338A is an F_4 selection from the cross F 23-71/Tam W-101 (32), and Newton is a 1978 cultivar release from the Kansas Agricultural Experiment Station (13). Both 77ST6338A and Newton have relatively large spikes.

Field Layout and Procedures

Populations 1 and 2 were planted in greenhouse flats on October 28, 1977. On November 18, 1977 the seedlings were transplanted into a Norge loam soil on the Agronomy Research Station at Stillwater. There were a total of 400 plants per population and all plants were spaced at 30 cm intervals. There were 20 plots per population and each plot consisted of two rows of 10 plants each. The F_2 plants in each population occupied 16 plots, one-half of them planted on either side of the four plots planted to parents and checks. Also, two guard rows were planted at the beginning and end of each population.

Both populations were topdressed with 135kg/ha ammonium nitrate on March 17, 1978. In late March the plants were sprayed with Malathion for greenbug control. The nursery was kept free of weeds. Supplemental irrigation was applied by a sprinkler system over a two-day period in early May. On June 27, 1978, 16 bordered plants/plot were harvested intact by pulling them out individually by their roots. For each population, this resulted in a total of 256 F_2 test plants, and 16 test plants of each parent and check entry.

Characters Measured

Eight traits were measured on each plant. Since the primary interest was in spike size, several different measures of the spike were taken to evaluate their usefulness as selection criteria. The three largest spikes were selected on each plant, and each measured separately. Measurements of plant, spike, and kernel characters were as follows:

Plant Height--The length in centimeters was recorded from the crown to the average of the tips of the three tallest spikes, excluding awns.

Plant Tiller Number--This trait was recorded as the number of fertile spikes per plant.

Spike Length--The distance from the base of the basal spikelet to the tip of the most distal spikelet, excluding awns, was measured to the nearest 0.1 cm for each of three selected spikes per plant.

Number of Spikelets/Spike--The number of spikelets on each of the three selected spikes per plant was counted.

Number of Kernels/Spike--The number of kernels in each of three selected spikes per plant was counted.

Number of Kernels/Spikelet--This trait was calculated on the basis of the two preceding measurements for each selected spike.

Kernel Weight--The kernels obtained from each selected spike were weighed to the nearest 0.1 g and divided by the number of kernels per spike. This gave a measure of kernel weight for each of the three selected spikes per plant. This trait was expressed as g/1000 kernels.

Plant Grain Yield--The total grain produced on each plant was weighed to the nearest 0.1 g.

Statistical Analysis

Statistical analyses were conducted at the O.S.U. computer center. A standard analysis of variance was conducted for each character in the F_2, parental, and check entries. The *corrected total* source of variation in the F_2 analysis had 767 degrees of freedom associated with it, owing to three spikes per plant on 256 F_2 plants. Plant height, tiller number, and grain yield were measured once per plant, and so for all two-way comparisons among these three traits the 767 degrees of freedom was a computing artifact. The *among plants* source of variation in the F_2 had 240 degrees of freedom associated with it. The *corrected total* source of variation in each parent and check entry had 47 degrees of freedom associated with it, due to three spikes per plant on 16 plants. The *among plants* source of variation in each parent and check was associated with 15 degrees of freedom. The phenotypic variance of each character was the *among plant* mean square in the analysis of variance table.

Heritability in the broad-sense was estimated for each character. These estimates were based on the following assumptions: a) that total phenotypic variance in the F_2 can be separated into a genetic component and an environmental component, and b) that the environmental component can be estimated by the variances of genotypically uniform parents (36). Allard (3) expressed broad-sense heritability quantitatively:

$$H = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_e^2}$$

where σ_g^2 is the genotypic variance and σ_e^2 is the environmental variance for a given character. The quantity $\sigma_g^2 + \sigma_e^2$ was estimated in the study by the phenotypic variance of the F_2 plants. The nonheritable variance, σ_e^2, was approximated by an average of the variances from the genetically uniform parent populations, $\frac{1}{2}(\hat{\sigma}_{e_1}^2 + \hat{\sigma}_{e_2}^2)$. The estimate of genotypic variance was then obtained by subtraction as follows: $\hat{\sigma}_g^2 = (\hat{\sigma}_g^2 + \hat{\sigma}_e^2) - \frac{1}{2}(\hat{\sigma}_{e_1}^2 + \hat{\sigma}_{e_2}^2)$. Additional estimates of environmental variance, $\hat{\sigma}_{e_3}^2$ and $\hat{\sigma}_{e_4}^2$, were obtained respectively from the checks 77ST6338A and Newton.

Phenotypic correlation coefficients were computed for all two-way comparisons among the eight traits using the F_2 data set. Two correlation coefficients were recorded, one based on 240 degrees of freedom from the *among plants* source of variation, and the other based on 767 degrees of freedom from the *corrected total* source of variation.

Overall means were computed for the F_2, parent, and check entries. The midparent value for each character was calculated, and the range for each character in the F_2 was found. Plot means were also computed to facilitate selection of the best F_2 plants in each plot, based on number of kernels per spike and acceptable kernel weight. This was a stratified grid type of selection in which 12.5% of the F_2 plants were taken. Progenies of these selected plants will be used in the Oklahoma Agricultural Experiment Station wheat breeding program for further selection studies on large spike characteristics.

CHAPTER IV

RESULTS AND DISCUSSION

Means

The overall entry means for Population 1 are presented in Table I, and those for Population 2 are presented in Table II. The range of expression for each character among F_2 plants is indicated by high and low values. Parent and midparent values, as well as those for the two check entries, are also included in these tables.

Population 1

Plant height in the F_2 ranged from 51.00 to 95.00 cm, with a mean of 73.20 cm (Table I). The F_2 mean was greater than the midparent value, while the tallest F_2 plant exceeded the mean of F 23-71, the taller parent, by a substantial margin. The range for plant tiller number in the F_2 was from 5.00 to 18.00 tillers per plant, with a mean of 9.88.

Spike length in the F_2 ranged from 6.80 to 13.33 cm, with a mean of 9.46 cm. The F_2 mean was greater than the midparent value for this trait (9.46 cm vs. 8.82 cm), and the F_2 plant with the highest value for spike length exceeded the mean of the F 23-71 parent by a substantial margin. A wide range in the number of kernels per spike (from 9.33 to 70.67) was expressed among the F_2 plants, while the F_2 mean for this character was close to the midparent value (41.99 vs. 41.78). The F_2 plant with the highest number of kernels per spike exceeded the parent and check mean values. F 23-71 was expected to have a high value for number of kernels per spike, but its value was lower than that of Caprock for this trait. The number of spikelets per spike in the F_2 ranged from 13.67 to 23.33, with a mean of 17.94 which was slightly below the midparent value. F 23-71 had, on the average, seven spikelets per spike more than Caprock, but F 23-71's advantage in this trait apparently did not result in a correspondingly high number of kernels per spike as discussed above. The F_2 plants expressed a range from 0.52 to 3.61 kernels per spikelet, with a mean of 2.35, which was close to the midparent value for this character. F 23-71 had the lowest mean value for this character, reflecting a lower level of spike fertility in comparison with Caprock, 77ST6338A, and Newton.

Kernel weight ranged from 15.23 to 63.89 g/1,000 kernels among the F_2 plants. The F_2 mean value of 29.91 g substantially surpassed both parental means for this character. It is of interest to note that the check cultivar Newton had the lowest mean for kernel weight, but had a relatively high mean number of kernels per spike. The F_2 plants ranged in grain yield from 1.20 to 20.70 g/plant, with a mean of 9.66 g. The F_2 mean for grain yield was slightly greater than that of Caprock.

Population 2

Plant height ranged from 51.00 to 92.00 cm, with a mean of 75.19 cm which was greater than the midparent value (Table II). The tallest F_2 plant exceeded the mean of F 23-71 by a substantial margin (92.00 cm vs. 76.38 cm). Plant tiller number ranged from 4.00 to 21.00, with a mean of 11.13 which was greater than the midparent value.

Spike length in the F_2 ranged from 6.90 to 12.27 cm. The F_2 mean for this trait was slightly greater than that of F 23-71, but not as great as the mean value of the check 77ST6338A. The number of kernels per spike in the F_2 ranged from 9.67 to 67.67 with a mean of 40.42 which was close to the midparent value. The F_2 plant with the highest value for this trait substantially exceeded the mean value of either parent. The two parental means were much closer than expected for this trait; Tam W-101, in particular, had an unexpectedly large number of kernels per spike. The check cultivar Newton had the largest mean for this trait.

The F_2 plants ranged from 14.67 to 24.00 spikelets per spike with a mean of 19.70, which was slightly larger than the midparent value. F 23-71 had substantially more spikelets per spike than did Tam W-101, but this advantage did not result in a substantially greater number of kernels per spike. The F_2 plants ranged from 0.58 to 3.51 kernels per spikelet, with a mean of 2.05 which was slightly below the midparent value for this trait. F 23-71 had the lowest number of kernels per spikelet, again reflecting its reduced fertility in relation to the checks.

Kernel weight ranged from 15.66 to 50.65 g/1,000 kernels with a mean of 30.06 g, which was slightly larger than the mean of Tam W-101. Newton, which had the highest number of kernels per spike, also had the lowest mean kernel weight. Grain yield ranged from 1.60 to 22.80 g/plant, with a mean of 10.79 g which was slightly above the midparent value. The highest yielding F_2 plant exceeded the mean value of Tam W-101 for grain yield by a substantial margin (22.80 vs. 12.29).

Comparison of Means in Populations 1 and 2

F 23-71 was fairly consistent in its expression of the eight characters observed in both Populations 1 and 2. Caprock and Tam W-101 both had larger than expected values for number of kernels per spike, while F 23-71 had a lower than expected value for this trait in both populations (Tables I and II). A differential response in the number of kernels per spike, by the adapted and unadapted parents may have been due, at least in part, to the 30 cm spacing of plants and the relatively late transplanting date. Kiesselback and Sprague (19) obtained results from a study involving Turkey wheat, which indicated that as seeding rate decreased, the number of kernels per spike increased, and that an increase in number of kernels per spike resulted when planting dates were later than normal. Conceivably, Caprock and Tam W-101 may have responded in this manner, while F 23-71 did not.

In both populations, F 23-71 had the lowest mean number of kernels per spikelet, indicating a reduced level of spike fertility. Partially sterile spikes were frequently observed in plants of F 23-71 as well as in F_2 plants in both populations. The nature of this spike fertility problem in F 23-71 is not known at this time. F 23-71 had the highest values for number of spikelets per spike of all the homozygous types studied, suggesting a potential for a high number of kernels per spike if fertility levels could be increased.

In both populations, the F_2 means for kernel weight were larger than corresponding means for parents or checks. The F_2 plants may have compensated for a low number of kernels per spike through the production of larger kernels. The check cultivar Newton had a relatively large number of kernels per spike in both populations, but had the lowest mean kernel weight in each population.

Variances and Heritabilities

Variances for eight characters in the F_2, parent, and check entries, along with broad-sense heritability estimates, are presented in Tables III and IV for Populations 1 and 2, respectively. The variances of each parent and check entry are presented in order to provide a comparison of estimates of environmental variance obtained for the parents. Broad-sense estimates of heritability are used by the plant breeder to give some indication of the portion of a character's observed variation that is due to genetic causes.

Population 1

The variances for all characters in the F_2 were greater than corresponding parental variances (Table III). In relation to F 23-71, Caprock exhibited a relatively low variance for plant height, but a rather large variance for grain yield per plant. For the other characters, Caprock and F 23-71 had variances of similar magnitude. The check cultivar Newton had relatively large variances for all characters except number of kernels per spikelet and kernel weight. For plant tiller number, Newton's variance was larger than the corresponding variance among the F_2 plants. This suggests that a larger amount of plant-to-plant variation was present in this check plot than was present in other plots within Population 1, for reasons unknown.

In terms of the magnitude of heritability estimates, the characters were ordered from low to high as follows: plant tiller number (.269), grain yield per plant (.414), kernel weight (.547), number of kernels per spike (.574), number of kernels per spikelet (.602), plant height (.702), number of spikelets per spike (.772), and spike length (.824). In this population the two yield components, number of kernels per spike and kernel weight, had higher heritability estimates than did grain yield per plant, but the heritability estimate obtained for plant tiller number was lower than that obtained for grain yield per plant.

Population 2

Variances in the F_2 exceeded the corresponding parental variances for five of the eight characters (Table IV). For plant tiller number and grain yield per plant, the Tam W-101 parental variances slightly exceeded the F_2 variances, while for number of spikelets per spike, the F 23-71 parental variance greatly exceeded that of the F_2. From Table IV it can be seen that the variance of F 23-71 for this trait was over twice the magnitude of the corresponding variance among the F_2 plants. The check entry 77ST6338A had a larger variance for number of kernels per spike than was found among the F_2 plants. These large variances suggest that large plant-to-plant differences existed for several different characters within the above mentioned check and parental plots. The check cultivar Newton, in contrast, had relatively low variances in this population; it had a particularly low variance for plant height.

A negative heritability estimate was calculated for the number of spikelets per spike in this population, and in accordance with accepted procedure, this was set at 0.00 (Table IV). The source of this negative value can be attributed to the extremely high variance for this character in F 23-71 and the relatively low corresponding variance among the F_2 plants. Had the variance of F 23-71 been of the same magnitude as that of Tam W-101, a positive heritability estimate of .207 would have been obtained for number of spikelets per spike. The remaining seven characters were ordered according to the magnitude of their heritability estimates from low to high as follows: plant tiller number (.194), grain yield per plant (.254), plant height (.414), spike length (.424), kernel weight (.441), number of kernels per spikelet (.460), and number of kernels per spike (.478). Two major components, number of kernels per spike and kernel weight, had higher heritability estimates than grain yield per plant, whereas, the heritability estimate for plant tiller number was lower than that of grain yield per plant.

Comparison of Variances and Heritabilities in Populations 1 and 2

The check cultivar Newton displayed large variances for most characters in Population 1, but had relatively small variances for the same characters in Population 2 (Tables III and IV). The reason for this differential response remains unknown. In Population 2, both parents had exceptionally large variances for several characters. Such large variances in parents and checks suggest wide plant-to-plant variation within the plots. Nass (23) noted that larger nongenetic differences among plants may be expected in space-planted plots than in more densely planted plots.

The variances among the F_2 plants in Population 1 were larger than corresponding F_2 variances in Population 2 for five of the eight characters. For all characters, except number of spikelets per spike, the variances were of similar magnitude in both populations for the parent F 23-71. The variances of Tam W-101, however, were larger than the variances of Caprock for all eight characters. As a result, the heritability estimates for all eight characters were larger in Population 1 than in Population 2.

According to the magnitude of their heritability estimates, the characters ranked somewhat differently in Populations 1 and 2. The number of spikelets per spike had a zero estimate of heritability in Population 2, while it was the second highest estimate in Population 1 with a value of 0.772. Apart from this anomaly, plant tiller number had the lowest heritability estimate in both populations with values of 0.269 and 0.194 in Populations 1 and 2, respectively. Grain yield per plant ranked next in both populations with values of 0.414 and 0.254 in Populations 1 and 2, respectively. In Population 1, kernel weight was next in magnitude with a value of 0.547. In Population 2, the kernel weight heritability estimate was of a slightly lower magnitude, 0.441, but ranked higher in order.

The number of kernels per spike had a heritability estimate of 0.574 in Population 1, while the corresponding estimate for this trait in Population 2 was 0.478. This estimate for number of kernels per spike was, however, the highest estimate obtained in Population 2. The number of kernels per spikelet was next in the order of its heritability in Population 1 with a value of 0.602, while in Population 2, a heritability estimate of 0.460 for this trait was the second largest value obtained. Plant height had a higher heritability estimate in Population 1 than in Population 2, with values of 0.702 and 0.414, respectively. The F_2 variance in Population 1 was greater than the corresponding variance in Population 2 for plant height, while Caprock's variance in Population 1 was quite small compared to the variance of Tam W-101 for plant height in Population 2. The difference between the variances of Caprock and Tam W-101 accounts largely for the different heritability estimates for plant height in Populations 1 and 2.

In Population 1 the number of spikelets per spike had the second highest heritability estimate with a value of 0.772. In Population 2 this character had a heritability estimate value of 0.000. The unusually low F_2 variance for this character in Population 2, combined with extreme variance of F 23-71 for this trait, resulted in this zero value. If the variance of Tam W-101 were used solely to estimate the environmental variance, σ_e^2, a heritability estimate of 0.207 would have been obtained for number of spikelets per spike in Population 2. This value is still lower than the heritability estimate obtained for grain yield in Population 2. The variance of number of spikelets per spike among the F_2 plants of Population 2 was less than half the magnitude of the corresponding variance in Population 1, for reasons unknown.

Spike length had the highest heritability estimate in Population 1, with a value of 0.824. In Population 2, however, spike length had only the fourth highest heritability estimate with a value of 0.424. The reason for this is that there was a larger F_2 variance for spike length in Population 1 than in Population 2, and also there were much larger parental variances for this trait in Population 2 than in Population 1.

Heritability estimates are dependent on several factors including the method by which they are estimated, the populations from which they are estimated, the units of measurement, and the environmental conditions during the test. The differences between the heritability estimates from Populations 1 and 2 serve to illustrate how such estimates are largely dependent upon the populations from which they are estimated. A number of investigators, however, have obtained heritability estimates by various methods in different winter wheat populations that do suggest that the components of yield are more highly heritable than is grain yield itself (2, 9, 21, 29).

Using parent-offspring regressions from a seven-parent diallel winter wheat cross, Fonseca and Patterson (9) obtained the following narrow-sense heritability estimates: grain yield (0.28 ± .15), kernel weight (0.44 ± .11), number of spikes per unit area (0.62 ± .07), and kernels per spike (0.72 ± .12). Using the variance component method, Sidwell (29) obtained narrow-sense heritability estimates as follows: tiller number (0.05 ± .17), grain yield (0.34 ± .36), kernels per spike (0.39 ± .21), and kernel weight (0.65 ± .06). Using Warner's (36) method, Alexander (2) found the following narrow-sense heritability estimates: grain yield (0.09 ± .32), tiller number (0.31 ± .27), kernels per spike (0.38 ± .25), and kernel weight (0.54 ± .23). The broad-sense heritability estimates for these traits in the present study were as follows for Populations 1 and 2, respectively: plant tiller number (0.269 and 0.194), grain yield per plant (0.414 and 0.254), kernel weight (0.547 and 0.441), and number of kernels per spike (0.574 and 0.478).

Smith (31) reported that recent investigations at the Oklahoma Agricultural Experiment Station indicate a ranking of traits based on their heritability estimates from low to high as follows: grain yield, tiller number, kernels per spike, and kernel weight. In the present study the heritability estimates for number of kernels per spike were consistently higher than those for kernel weight, while the heritability estimates for both of these yield components were larger than heritability estimates for grain yield per plant. In contrast to the results obtained by Smith (31), plant tiller number in this study had a lower heritability estimate than grain yield per plant in both populations.

Correlations

Although the primary interest in this study concerned relationships involving spike characters, correlation coefficients were computed for all two-way comparisons in the F_2 data set of each population. Two correlation coefficients were computed for each two-way comparison: one from the *among plants* source of variation, and the other from the *corrected total* source of variation. These two values were in close agreement in most cases. The correlation coefficients from Populations 1 and 2 are recorded in Tables V and VI, respectively.

Population 1

High correlation coefficients were obtained between number of kernels per spike and number of kernels per spikelet (Table V). Correlations of intermediate magnitude were found between number of kernels per spike and grain yield, and between number of kernels per spikelet and grain yield. Positive correlations of intermediate magnitude were also obtained for two-way comparisons among the following three traits: plant height, spike length, and number of spikelets per spike. A statistically significant low negative correlation was found between number of spikelets per spike and kernel weight. All other correlations involving spike characters were either positive in sign and low in magnitude or negative and nonsignificant.

Correlations involving the three major yield components with grain yield were also of interest. Plant tiller number had a high positive correlation with yield. The correlation between number of kernels per spike and yield was positive in sign and intermediate in magnitude, while that of kernel weight and yield was positive but low in magnitude.

Population 2

High correlation coefficients were found between the number of kernels per spike and the number of kernels per spikelet (Table VI). Correlation coefficients of intermediate magnitude were found between number of kernels per spike and grain yield, and between number of kernels per spikelet and grain yield. Correlations of intermediate magnitude were found for two-way comparisons among the three following traits: plant height, spike length, and number of spikelets per spike. In this population correlations of intermediate magnitude were also found between number of kernels per spike and number of spikelets per spike. All other correlations involving spike characters were either positive in sign and low in magnitude or nonsignificant.

The correlation between plant tiller number and grain yield was positive in sign and high in magnitude. The correlation between grain yield and number of kernels per spike was positive in sign and intermediate in magnitude, while the correlation between grain yield and kernel weight was positive in sign but low in magnitude.

Discussion of Correlation Values in Populations 1 and 2

The absence of any large negative correlations involving the eight characters (Tables V and VI) is in agreement with Adams' (1) suggestion that such characters would not be expected to show negative associations in space-planted conditions. There was very good agreement in the sign and magnitude of correlation coefficients observed in Population 1 with those of Population 2, suggesting that the characters in both populations responded in the same direction to prevailing environmental conditions.

The highest correlation in both populations occurred between number of kernels per spike and number of kernels per spikelet. A high correlation here was expected since both characters can be considered as having a common basis. This contrasts to the lower correlation values obtained between number of kernels per spike and number of spikelets per spike in which spike fertility could have been a factor. The number of kernels per spike was more closely associated with spikelet fertility than with the number of spikelets per spike. This may be indicative of the wheat plant's potential to fill the third floret under suitable environmental conditions. Plant height was correlated with both spike length and number of spikelets per spike with coefficients of intermediate magnitude. If a cause and effect relationship were to be postulated here, then the breeder might encounter some problems in combining short stature with large spikes.

Plant tiller number was most highly correlated with grain yield per plant in both populations. This result was expected with spaced plants.

The number of kernels per spike had the next highest correlation with grain yield. Higher heritability estimates were found for number of kernels per spike than for plant tiller number or grain yield. Again, assuming a cause and effect relationship, these results suggest that in these populations, selection for grain yield per plant might best be approached indirectly by selecting for number of kernels per spike.

Stratified Grid Selection

The two best F_2 plants in each plot were selected based on number of kernels per spike and acceptable kernel weight. These selections are recorded in Tables VII and VIII along with the plot means. The selection of two plants per plot resulted in a stratified grid type of selection in which 12.5% of the F_2 plants were taken. Progenies of these selected plants will be used in the Oklahoma Agricultural Experiment Station wheat breeding program for further selection studies on large spike characteristics.

CHAPTER V

SUMMARY AND CONCLUSIONS

Two F_2 populations, originating from winter wheat crosses made in the greenhouse, were space-planted on the Agronomy Research Station at Stillwater and grown during the 1977-78 crop season. The primary objectives were to estimate heritabilities and to study the interrelationships of several traits dealing with spike size. The two populations had as a common parent the germplasm line F 23-71, which was developed in Romania and is the best genotype that has been evaluated in Oklahoma regarding number of spikelets per spike. The adapted parents, Caprock (Population 1) and Tam W-101 (Population 2) are hard red winter wheats that were released from the Texas Agricultural Experiment Station in 1969 and 1971, respectively. In Population 1 data was gathered on: a) 256 F_2 plants from the cross Caprock/F 23-71, b) 16 plants of each homozygous parent Caprock and F 23-71, and c) 16 plants each of the two checks 77ST6338A and Newton. In Population 2 data was gathered on: a) 256 F_2 plants from the cross Tam W-101/F 23-71, b) 16 plants of each homozygous parent Tam W-101 and F 23-71, and c) 16 plants of each of the two checks 77ST6338A and Newton.

Although primary interest was in measures of spike size, the following eight plant, spike, and kernel characters were measured: plant height, plant tiller number, spike length, number of kernels per spike, number of spikelets per spike, number of kernels per spikelet, kernel weight, and grain yield per plant. All measurements were on a per plant basis, and in addition the five spike and kernel characters were based on the three best spikes per plant. Means were computed and a standard analysis of variance was conducted for each character in the F_2, parent, and check entries. Correlation coefficients were also computed for all two-way comparisons in the F_2 data sets.

Broad-sense heritabilities were calculated for all eight characters as estimates of the ratio of genetic variance to total variance. The F_2 variances were taken as estimates of total variance. The average obtained from the two parental variances was used to approximate environmental variance for the calculation of heritability estimates. An estimate of genetic variance was obtained by subtraction of the approximated environmental variance from the total variance in the F_2.

In Population 1 the variances of the two parents were of similar magnitude for seven of the eight characters, while corresponding F_2 variances were greater than parental variances for all characters. In Population 2, however, the variances of Tam W-101 exceeded the F_2 variances for plant tiller number and grain yield, while the variance of F 23-71 greatly exceeded the F_2 variance for number of spikelets per spike. Except for number of spikelets per spike, the variances of F 23-71 were consistent for both populations. In contrast, the variances of Tam W-101 were larger than the variances of Caprock for all eight characters. As a result, the heritability estimates for all eight characters were larger in Population 1 than in Population 2.

The eight characters ranked somewhat differently in Populations 1 and 2, according to the magnitude of their heritability estimates. In Populations 1 and 2, respectively, heritabiltiy estimates were obtained as follows: plant tiller number (0.269 and 0.194), grain yield per plant (0.414 and 0.254), number of kernels per spike (0.574 and 0.478), number of kernels per spikelet (0.602 and 0.460), plant height (0.702 and 0.414), number of spikelets per spike (0.772 and 0.000), and spike length (0.824 and 0.424). The value 0.000 obtained in Population 2 for number of spikelets per spike is due to the unaccountably high variance of the F 23-71 parent.

According to their heritability coefficients, the spike characters were not ranked in consistent order in both populations. Spike length had the highest heritability estimate in Population 1, but only the fourth highest in Population 2. Two traits, number of spikelets per spike and number of kernels per spikelet, both components of spike size, had higher heritability estimates than did number of kernels per spike in Population 1. In Population 2, however, the number of kernels per spike had the highest heritability estimate of all eight characters.

Based on the heritability estimates from both populations, the number of kernels per spike had the most consistent heritability estimate of those traits dealing with spike size. In both populations, two major yield components, number of kernels per spike and kernel weight, had higher heritability estimates than grain yield per plant. The other major yield component, plant tiller number, had a lower heritability estimate than grain yield per plant in both populations.

There was very good agreement in sign and magnitude of correlation coefficients observed in Population 1 with those in Population 2, suggesting that the characters in both populations responded in the same direction to prevailing environmental conditions. The absence of any large negative correlations involving the eight characters is in agreement with Adams' (1) suggestion that such characters would not be expected to show strong negative associations in space-planted conditions. The highest correlation in both populations occurred between the number of kernels per spike and the number of spikelets per spike. In contrast, correlation coefficients between spike length and number of kernels per spike, and between number of spikelets per spike and number of kernels per spike were positive in sign, but low to intermediate in magnitude. This may have been due, in part, to the frequent occurrence of partially sterile spikes in the F_2 plants.

Plant height was positively correlated with both spike length and number of spikelets per spike with coefficients of intermediate magnitude. If a cause and effect relationship were to be postulated here, then the breeder might encounter some problems in combining short stature with large spikes. Correlations among the three major yield components were also of interest. Plant tiller number had a high positive correlation with grain yield. The correlation between number of kernels per spike and yield was positive in sign and intermediate in magnitude, while that between kernel weight and yield was positive but low in magnitude.

Of the three major yield components, number of kernels per spike had the highest broad-sense heritability estimate. Also, the number of kernels per spike was second only to plant tiller number in the magnitude of its correlation with grain yield. Assuming a cause and effect relationship here, these results suggest that selection for grain yield per plant might be best approached indirectly by selecting for number of kernels per spike.

In conclusion, the most useful trait dealing with spike size was the number of kernels per spike, since its heritability estimate was more consistent from one population to the other than those of the other spike characters.

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APPENDIX

TABLE I

RANGES AND MEANS OF F_2 PLANTS ALONG WITH PARENT AND CHECK VALUES FOR EIGHT CHARACTERS IN POPULATION 1 (CAPROCK/F 23-71)

Entry		Plant Height (cm)	Plant Tiller Number	Spike Length (cm)	Number Kernels/ Spike	Number Spikelets/ Spike	Number Kernels/ Spikelet	Kernel Weight (g/1000)	Grain Yield (g/plant)
F_2	High	95.00	18.00	13.33	70.67	23.33	3.61	63.89	20.70
	Low	51.00	5.00	6.80	9.33	13.67	0.52	15.23	1.20
	Mean	73.20	9.88	9.46	41.99	17.94	2.35	29.91	9.66
Caprock		57.44	10.31	7.90	42.67	14.69	2.90	25.75	9.53
F 23-71		78.50	8.94	9.73	40.88	22.10	1.84	24.81	7.14
Midparent		67.97	9.63	8.82	41.78	18.40	2.37	25.28	8.34
77ST6338A		69.69	7.81	11.58	53.98	20.52	2.63	22.33	7.17
Newton		70.13	10.69	9.94	52.48	19.90	2.63	21.52	10.22

TABLE II

RANGES AND MEANS OF F_2 PLANTS ALONG WITH PARENT AND CHECK VALUES FOR EIGHT CHARACTERS IN POPULATION 2 (TAM W-101/F 23-71)

Entry		Plant Height (cm)	Plant Tiller Number	Spike Length (cm)	Number Kernels/ Spike	Number Spikelets/ Spike	Number Kernels/ Spikelet	Kernel Weight (g/1000)	Grain Yield (g/plant)
F_2	High	92.00	21.00	12.27	67.67	24.00	3.51	50.65	22.80
	Low	51.00	4.00	6.90	9.67	14.67	0.58	15.66	1.60
	Mean	75.19	11.13	9.99	40.42	19.70	2.05	30.06	10.79
Tam W-101		65.88	12.25	8.69	40.10	16.10	2.49	29.41	12.29
F 23-71		76.38	9.13	9.83	41.48	22.40	1.86	24.57	7.82
Midparent		71.13	10.69	9.26	40.79	19.25	2.18	26.99	10.06
77ST6338A		69.88	8.69	11.63	48.92	21.56	2.27	22.36	7.76
Newton		66.56	10.00	9.88	54.23	21.23	2.56	19.61	9.20

TABLE III

VARIANCES AND BROAD-SENSE HERITABILITY ESTIMATES FOR EIGHT CHARACTERS IN POPULATION 1 (CAPROCK/F 23-71)

Entry	Variance Component Estimated	Plant Height	Plant Tiller Number	Spike Length	Number Kernels/ Spike	Number Spikelets/ Spike	Number Kernels/ Spikelet	Kernel Weight (x 1000)	Grain Yield/ Plant
F_2	$\hat{\sigma}_g^2 + \hat{\sigma}_e^2$	55.33	8.96	3.031	327.50	12.393	0.8910	0.1010	16.607
Caprock	$\hat{\sigma}_{e_1}^2$	6.66	6.50	0.427	105.82	2.421	0.3972	0.0318	11.502
F 23-71	$\hat{\sigma}_{e_2}^2$	26.27	6.60	0.640	173.24	3.232	0.3117	0.0596	7.965
78ST6338A	$\hat{\sigma}_{e_3}^2$	25.30	5.90	2.545	210.29	5.999	0.3098	0.0148	5.837
Newton	$\hat{\sigma}_{e_4}^2$	40.25	9.56	2.253	232.09	8.388	0.3450	0.0488	12.609
Heritability ≃ $\frac{F_2 - \frac{1}{2}(\hat{\sigma}_{e_1}^2 + \hat{\sigma}_{e_2}^2)}{F_2}$		.702	.269	.824	.574	.772	.602	.547	.414

TABLE IV

VARIANCES AND BROAD-SENSE HERITABILITY ESTIMATES FOR EIGHT CHARACTERS IN POPULATION 2 (TAM W-101/F 23-71)

Entry	Variance Component Estimated	Plant Height	Plant Tiller Number	Spike Length	Number Kernels/ Spike	Number Spikelets/ Spike	Number Kernels/ Spikelet	Kernel Weight (x 1000)	Grain Yield/ Plant
F_2	$\hat{\sigma}_g^2 + \hat{\sigma}_e^2$	47.75	10.04	2.764	349.23	6.092	0.7768	0.0960	19.01
Tam W-101	$\hat{\sigma}_{e_1}^2$	26.65	10.73	1.395	176.08	4.832	0.5827	0.0471	21.84
F 23-71	$\hat{\sigma}_{e_2}^2$	29.32	5.45	1.791	188.58	13.476	0.2557	0.0603	6.51
77ST6338A	$\hat{\sigma}_{e_3}^2$	13.98	5.70	0.814	364.33	5.276	0.7148	0.0441	12.55
Newton	$\hat{\sigma}_{e_4}^2$	6.66	4.53	0.817	141.72	5.499	0.2314	0.0352	7.40
Heritability $\simeq \dfrac{F_2 - \frac{1}{2}(\hat{\sigma}_{e_1}^2 + \hat{\sigma}_{e_2}^2)}{F_2}$		.414	.194	.424	.478	.000	.460	..441	.254

TABLE V

CORRELATION COEFFICIENTS AMONG EIGHT CHARACTERS FROM THE F_2 DATA SET IN POPULATION 1 (CAPROCK/F 23-71)

Character	Grain Yield/ Plant	Kernel Weight	Number Kernels/ Spikelet	Number Spikelets/ Spike	Number Kernels/ Spike	Spike Length	Plant Tiller Number
Plant Height	.342** .352**	.286** .213**	.057 .073	.576** .501**	.302** .276**	.666** .620**	.145* .149**
Plant Tiller Number	.828** .828**	.146* .107**	.338** .286**	.112 .121**	.357** .312**	-.022 .007	
Spike Length	.112 .130**	.104 .104**	-.110 -.022	.649** .606**	.178** .232**		
Number Kernels/Spike	.637** .554**	-.077 -.031	.896** .903**	.367** .356**			
Number of Spikelets/Spike	.201** .194**	-.197** -.171**	-.072 -.066				
Number of Kernels/Spikelet	.595** .510**	.011 .045					
Kernel Weight	.318** .244**						

*,** Significantly different from zero at the 0.05 and 0.01 levels, respectively.

Upper values based on 240 d.f. from the *among plants* source of variation.
Lower values based on 767 d.f. (3 spikes/plant) from the *corrected total* source of variation.

TABLE VI

CORRELATION COEFFICIENTS AMONG EIGHT CHARACTERS FROM THE F_2 DATA SET IN POPULATION 2 (TAM W-101/F 23-71)

Character	Grain Yield/ Plant	Kernel Weight	Number Kernels/ Spikelet	Number Spikelets/ Spike	Number Kernels/ Spike	Spike Length	Plant Tiller Number
Plant Height	.326**	.441**	.172*	.431**	.261**	.512**	-.017
	.342**	.334**	.148**	.335**	.224**	.461**	.011
Plant Tiller Number	.745**	.046	.215**	.079	.217**	.083	
	.740**	.037	.194**	.063	.198**	.063	
Spike Length	.277**	.303**	.121	.451**	.223**		
	.263**	.223**	.127**	.433**	.235**		
Number Kernels/Spike	.608**	-.117	.964**	.442**			
	.526**	.008	.959**	.334**			
Number Spikelets/Spike	.296**	.043	.200**				
	.240**	.014	.070				
Number Kernels/Spikelet	.583**	-.126					
	.490**	.013					
Kernel Weight	.255**						
	.205**						

*, ** Significantly differently from zero at the 0.05 and 0.01 levels, respectively.

Upper values based on 240 d.f. from the *among plants* source of variation.
Lower values based on 767 d.f. (3 spikes/plant) from the *corrected total* source of variation.
Correlations involving plant height based on 210 and 671 d.f., respectively.

TABLE VII

STRATIFIED GRID SELECTION OF F_2 PLANTS IN POPULATION 1 (CAPROCK/F 23-71) WITH CORRESPONDING VALUES FOR EIGHT CHARACTERS OF THE TWO PLANTS SELECTED IN EACH PLOT

Plot No.	Plant No.	Plant Height (cm)	Plant Tiller No.	Spike Length (cm)	No. Kernels/ Spike	No. Spikelets/ Spike	No. Kernels/ Spikelet	Kernel Weight (g/1000)	Grain Yield (g/plant)
1	1	77.0	9.0	10.2	65.0	18.3	3.56	29.2	10.20
1	13	76.0	13.0	9.3	56.3	20.0	2.82	29.9	14.30
1	Plot Mean	70.8	10.2	9.3	43.4	17.7	2.46	29.6	9.71
2	1	80.0	12.0	10.3	53.3	23.0	2.30	28.5	14.60
2	4	74.0	5.0	10.6	70.7	23.3	3.03	25.5	7.10
2	Plot Mean	69.3	10.4	9.5	42.1	18.8	2.24	29.8	9.81
3	7	79.0	16.0	9.2	54.0	20.7	2.61	36.5	20.30
3	11	72.0	14.0	8.5	53.0	18.0	2.94	24.9	13.10
3	Plot Mean	72.1	10.6	9.1	40.5	17.3	2.33	32.3	10.54
4	12	79.0	14.0	9.7	62.7	17.3	3.61	31.5	18.30
4	15	77.0	17.0	8.9	56.7	19.7	2.89	31.0	14.80
4	Plot Mean	73.3	10.7	9.4	42.0	18.1	2.33	29.6	10.13
5	2	84.0	14.0	10.4	43.7	20.0	2.18	42.6	17.20
5	16	72.0	17.0	9.3	54.0	17.0	3.18	33.9	20.70
5	Plot Mean	77.0	11.1	9.8	41.8	18.1	2.31	32.4	11.70
6	1	69.0	18.0	9.0	55.3	18.3	3.02	29.5	18.90
6	15	78.0	8.0	9.6	52.7	18.7	2.83	30.2	9.80
6	Plot Mean	72.8	10.3	9.7	42.9	18.1	2.39	27.8	9.52

TABLE VII (Continued)

Plot No.	Plant No.	Plant Height (cm)	Plant Tiller No.	Spike Length (cm)	No. Kernels/ Spike	No. Spikelets/ Spike	No. Kernels/ Spikelet	Kernel Weight (g/1000)	Grain Yield (g/plant)
7	3	79.0	13.0	10.5	60.3	17.7	3.42	33.1	18.10
7	4	72.0	17.0	9.8	48.7	17.3	2.82	38.5	20.40
7	Plot Mean	75.6	10.4	10.0	41.4	18.4	2.25	31.9	10.66
8	3	71.0	15.0	9.3	64.0	18.0	3.56	33.8	19.50
8	13	92.0	11.0	11.8	66.3	19.3	3.41	28.2	10.80
8	Plot Mean	76.8	10.7	9.8	48.4	18.8	2.59	27.2	10.56
13	4	71.0	13.0	9.4	51.0	19.0	2.69	26.8	13.40
13	8	68.0	15.0	8.6	54.0	17.7	3.08	24.5	13.50
13	Plot Mean	69.8	9.4	8.9	38.7	17.5	2.19	26.8	8.26
14	7	81.0	10.0	10.8	56.7	18.0	3.17	27.4	11.40
14	15	79.0	7.0	9.5	50.7	17.7	2.88	38.6	10.10
14	Plot Mean	73.6	9.0	9.2	41.2	17.6	2.34	31.6	9.08
15	8	77.0	6.0	9.4	61.0	17.3	3.52	39.9	10.40
15	15	77.0	10.0	9.2	52.3	17.0	3.08	41.4	16.50
15	Plot Mean	73.6	8.7	9.4	46.2	17.8	2.61	31.6	9.52
16	7	87.0	14.0	10.5	55.7	17.3	3.20	36.4	18.20
16	16	72.0	9.0	8.8	53.7	16.7	3.22	39.1	12.40
16	Plot Mean	75.2	10.0	9.5	44.7	17.5	2.55	30.2	9.93
17	4	75.0	7.0	9.5	58.0	19.3	3.01	34.9	10.80
17	11	95.0	10.0	9.7	51.3	20.0	2.57	32.5	15.80
17	Plot Mean	77.9	9.1	9.9	41.0	18.2	2.27	30.1	9.01

TABLE VII (Continued)

Plot No.	Plant No.	Plant Height (cm)	Plant Tiller No.	Spike Length (cm)	No. Kernels/ Spike	No. Spikelets/ Spike	No. Kernels/ Spikelet	Kernel Weight (g/1000)	Grain Yield (g/plant)
18	2	77.0	11.0	11.1	61.7	21.7	2.84	22.6	13.00
18	7	87.0	11.0	10.6	55.7	18.0	3.09	63.9	17.50
18	Plot Mean	70.8	10.1	9.6	41.4	18.3	2.28	29.5	9.51
19	1	80.0	7.0	11.6	49.7	22.0	2.26	27.5	7.90
19	5	78.0	6.0	9.7	56.3	20.7	2.73	24.2	7.10
19	Plot Mean	71.1	8.4	9.3	39.1	17.5	2.24	28.2	7.79
20	5	75.0	15.0	9.3	45.0	16.7	2.71	33.9	17.10
20	16	68.0	9.0	8.8	47.7	16.3	2.92	32.1	11.50
20	Plot Mean	71.6	9.3	9.1	37.3	17.4	2.16	29.7	8.88

TABLE VIII

STRATIFIED GRID SELECTION OF F_2 PLANTS IN POPULATION 2 (TAM W-101/F 23-71) WITH CORRESPONDING VALUES FOR EIGHT CHARACTERS OF THE TWO PLANTS SELECTED IN EACH PLOT

Plot No.	Plant No.	Plant Height (cm)	Plant Tiller No.	Spike Length (cm)	No. Kernels/ Spike	No. Spikelets/ Spike	No. Kernels/ Spikelet	Kernel Weight (g/1000)	Grain Yield (g/plant)
21	9	75.0	7.0	10.0	53.0	19.0	2.80	34.5	9.30
21	16	80.0	14.0	10.0	57.0	22.3	2.57	30.4	22.80
21	Plot Mean	71.6	10.1	10.0	40.0	19.5	2.04	31.1	9.66
22	3	75.0	11.0	10.7	66.7	20.7	3.23	28.6	15.70
22	12	80.0	14.0	10.8	57.7	21.0	2.75	31.7	19.30
22	Plot Mean	72.3	11.4	10.1	43.1	20.0	2.16	29.4	11.58
23	2	84.0	11.0	11.4	50.0	24.0	2.07	36.9	15.70
23	13	89.0	8.0	11.8	61.3	23.0	2.69	29.4	11.40
23	Plot Mean	76.2	10.3	10.7	41.4	20.4	2.03	30.2	11.22
24	2	89.0	12.0	10.2	50.7	19.7	2.57	37.0	14.80
24	7	80.0	12.0	10.6	54.3	21.0	2.58	32.2	12.50
24	Plot Mean	79.6	12.6	10.4	44.3	20.5	2.17	33.5	13.52
25	2	85.0	12.0	9.5	55.3	19.0	2.91	32.7	18.90
25	15	72.0	13.0	11.6	61.3	21.0	2.94	26.5	13.60
25	Plot Mean	76.9	10.9	10.0	43.2	19.6	2.17	29.5	12.33
26	6	87.0	6.0	9.3	56.3	19.7	2.88	28.9	9.10
26	9	76.0	11.0	9.4	49.3	19.0	2.60	31.7	13.60
26	Plot Mean	77.6	10.6	10.1	40.4	19.6	2.05	28.0	10.18

TABLE VIII (Continued)

Plot No.	Plant No.	Plant Height (cm)	Plant Tiller No.	Spike Length (cm)	No. Kernels/ Spike	No. Spikelets/ Spike	No. Kernels/ Spikelet	Kernel Weight (g/1000)	Grain Yield (g/plant)
27	7	80.0	11.0	10.1	50.0	19.3	2.59	35.5	14.10
27	8	79.0	10.0	11.6	64.3	18.3	3.51	24.9	12.50
27	Plot Mean	77.1	11.0	10.2	40.3	19.0	2.12	30.4	10.86
28	8	†	14.0	11.6	49.3	20.0	2.47	31.2	13.70
28	9	†	21.0	11.1	65.7	21.3	3.11	25.2	17.60
28	Plot Mean	†	12.9	10.2	42.8	19.5	2.20	30.8	11.85
33	11	81.0	16.0	9.5	51.7	19.7	2.63	32.8	17.50
33	12	80.0	9.0	11.1	60.3	19.0	3.18	34.3	12.90
33	Plot Mean	76.1	11.0	9.8	42.4	19.5	2.18	30.0	11.24
34	7	†	16.0	10.1	58.3	20.0	2.92	33.8	21.50
34	13	†	9.0	10.1	47.7	17.7	2.72	29.9	9.80
34	Plot Mean	†	12.1	9.5	38.5	19.4	1.99	28.9	10.78
35	2	78.0	19.0	10.3	54.3	18.7	2.92	31.5	17.50
35	6	77.0	13.0	11.1	60.7	22.7	2.69	29.2	19.20
35	Plot Mean	73.4	12.8	9.8	39.4	19.6	2.00	28.7	11.78
36	1	79.0	10.0	9.9	50.7	18.7	2.72	28.1	9.90
36	10	74.0	15.0	9.8	63.7	19.7	3.24	27.8	19.10
36	Plot Mean	73.4	11.5	9.5	40.5	19.8	2.05	27.3	9.59
37	8	80.0	13.0	10.2	47.0	20.0	2.35	35.9	17.50
37	15	81.0	8.0	9.6	45.0	22.0	2.04	34.1	7.90
37	Plot Mean	79.0	10.7	10.0	37.7	20.0	1.88	31.6	9.86

TABLE VIII (Continued)

Plot No.	Plant No.	Plant Height (cm)	Plant Tiller No.	Spike Length (cm)	No. Kernels/ Spike	No. Spikelets/ Spike	No. Kernels/ Spikelet	Kernel Weight (g/1000)	Grain Yield (g/plant)
38	1	77.0	11.0	8.7	50.7	21.0	2.41	28.8	11.20
38	7	78.0	8.0	11.7	48.3	22.0	2.20	34.0	12.20
38	Plot Mean	72.5	9.8	9.7	33.4	19.6	1.69	29.9	8.18
39	1	79.0	13.0	11.6	50.7	21.0	2.43	34.4	16.80
39	10	79.0	6.0	11.3	48.3	20.7	2.34	29.1	7.10
39	Plot Mean	73.3	10.8	9.7	41.5	19.8	2.10	29.3	10.27
40	4	82.0	13.0	11.6	44.0	21.7	2.03	33.3	11.40
40	13	78.0	7.0	9.5	53.3	19.3	2.77	25.7	7.40
40	Plot Mean	73.5	9.9	10.1	37.6	19.5	1.92	30.4	9.51

†Height data missing for plots 28 and 34.

VITA[2]

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Master of Science

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