SELECTION FOR KERNEL WEIGHT AND ITS INFLUENCE ON YIELD AND YIELD COMPONENTS IN A SIMPLE WHEAT (TRITICUM AESTIVUM L.) CROSS

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INTRODUCTION

Grain yield is the end product of growth and development and is the result of environmental and genotypic interactions. Frey (1971) and Nickell and Grafius (1969) feel that to maximize yield, varieties and environments have to be improved simultaneously. One way of determining the effects of the environment on yield, is by observing the components of yield. Yield components have been used in crosses by many investigators to increase yield. Parental materials should be selected on their component attributes, thereby allowing their progeny to carry the optimum combination of yield components.

It is of interest to know if varieties should be developed which tend to produce more spikes per plant or varieties with fewer but larger spikes. Another item of importance is the knowledge of whether the number of spikes can be increased without decreasing the kernel size.

In 1965, a kernel weight study in wheat was initiated to determine the relationship of kernel weight with other yield components for several environments in Kansas. The desired end product was maximum yield and large, plump kernels. Crosses were made between a large seeded variety, 'Apache', and a small seeded variety, 'Shawnee'. Shawnee also usually exceeds Apache in spikes per unit area and in kernels per spike.

Selections from these crosses were studied in several kernel-weight classes. The selections were evaluated for yield, yield components, height, test weight, maturity, leaf rust and Hessian fly. The knowledge of the relationship between these characteristics in hard-red-winter wheat would be useful in determining what variety would produce the greatest yield for a certain environment.

LITERATURE REVIEW

Yield Components

The inherent capacity for yield of hard-red-winter wheat may be expressed by the following yield components: (1) number of spikes per unit area, (2) number of kernels per spike, and (3) average weight per kernel (Engledow et al., 1923), (Woodworth, 1931), (Quisenberry, 1928), (Poehlman, 1959), (Copp et al., 1952), (Grafius, 1956), (Stickler and Pauli, 1961), (Johnson et al., 1966), and (Rasmusson and Cannell, 1970).

Yield of small grain has been described as the product of yield components. Grafius (1956) represented yield as a geometric construction, namely a rectangular parallelopiped whose three dimensions were determined by the three components of yield. An increase in any one of the three components would result in an increase in total yield, provided there was no corresponding decrease in the other two components. Generally, in nature, as one component increases, one or more of the other components decrease. Grafius described a universal variety as one that must either resist change or adjust favorably to changes in the environment. The longest edge of the parallelopiped of a universal variety is the one most subject to change and the changes in dimensions or components tend to counterbalance one another.

Another component was suggested by Laude (1938), namely the number of plants per acre. Whitehouse et al. (1958), and Kronstad and Foote (1964) also considered number of spikelets per spike and number of kernels per spikelet to be components of yield.

Reports indicated that environmental and cultural conditions greatly affect the means, standard deviations, and correlation coefficients of yield components. Love and Leighty (1914), Arny and Garber (1918), Sprague (1926), and Jain and Aulakh (1971) found, in general, the standard deviation tends to follow the mean. They also noted that variability was greatest when growing conditions were favorable for the plant, except variation in average weight of the kernels was noted by Love and Leighty (1914) as being greatest under unfavorable growing conditions. When environmental conditions were unfavorable for plant development, Love and Leighty (1914) found yield was lowered, not by reduction in average weight per kernel or number of spikelets produced but by a reduction in number of kernels per plant. Quisenberry (1928) also found kernels per head to be more significant in influencing yield than number of tillers or kernel weight.

Kernel weight has been shown to be the grain-yield component least influenced by the environment (Quisenberry, 1928), (Immer et al., 1928), (Smith, 1936), (Copp and Wright, 1952), (Palmer, 1952), and (Weibel, 1956). On the other hand, Sharma and Knott (1964) had great variability in seed weight probably as a result of small differences in available moisture.

Inheritance of Kernel Weight

The utilization of the components of yield approach in research should be most effective if the components are highly heritable, if they are genetically independent and if they are highly correlated to yield. Paroda and Joshi (1970) have shown that kernel weight is genetically more stable than any other component of grain yield. Kernel weight is highly heritable and has a high genetic advance (Sharma and Knott, 1964) and (Jain and Aulakh, 1971). There are different opinions as to the number of genes that control the inheritance of kernel weight. Kernel weight is thought to be inherited monogenicly (Worzella, 1942); trigenicly (Janowski, 1935) and (Boyce, 1948); tetragenicly (Boyce, 1948) and (Sharma and Knott, 1964); and multigenicly (Clark, 1924), (Aamodt, 1935), (Torrie, 1936), (Worzella and Cutler, 1939), (Kaspira and Unrau, 1957), and (Paroda and Joshi, 1970). Hence this character is of great value to the breeder for selection. In wheat, kernel weight was the most effective yield component in selection for Smith (1936).

Correlation Studies

Selection for one of the components may fail to result in yield increases due to negative associations among components (Frankel, 1935). Adams (1967) reported that negative correlations among yield components are wide spread among major crop plants, particularly under various kinds of environmental stress. He thought the negative correlations were developmental rather than genetic per se, and postulated them to be caused by genetically independent components, developing in a sequential pattern, that are free to vary in response to either a limited constant input of metabolites or an oscillatory input of metabolites such that the input is limiting at critical stages in the developmental sequence of the plant. Further research by Adams and Grafius (1971) showed that balance among yield components in crop plants in a specific environment was achieved primarily through the oscillatory response of sequential components to limited resources. Adams (1967) found low or near zero correlations among yield components in noncompetitive navy bean plants spaced 45 cm. apart, but significant negative correlations occurred in those spaced at 7.5 cm. The negative correlations must have arisen in response to competitional operating forces on developing components;

therefore showing the environmental effects over the genetic make up of the plant. This is known as component compensation as documented by Duarte (1966), Adams (1967), Nickell and Grafius (1969), Knott and Talukdar (1971), Thomas et al. (1971a, b) and Adams and Grafius (1971). Component compensation remains as one of the impediments to progress in selecting for a complex trait such as yield.

Correlation of kernel weight with yield, other yield components, and agronomic characters has been reported by several investigators. Rasmusson and Cannell (1970), working with barley, reported kernel weight to be significantly related to yield. Significant negative correlations were found for kernel weight with spikes per plot and with kernels per spike. The authors calculated phenotypic correlations for two populations in each of the F_4 and F_5 generations. Yield with spikes per plot was found to be positive and significantly correlated in all but one of the F_5 generations and yield with kernels per spike was positive and significantly correlated in the F_4 generation and significantly negatively correlated in one population of the F_5 generation. Spikes per plot was slightly positively, zero, slightly negatively or significantly negatively correlated to kernels per spike. Whitehouse et al. (1958) obtained approximately the same correlations working with nineteen varieties of wheat. Correlations between yield components and other agronomic characters varied greatly in the work of various investigators.

Knott and Talukdar (1971) reported a highly significant association between kernel weight and yield in one test in 1968 and a positive but not significant correlation in another test. They found a highly significant negative correlation between kernel weight and kernels per plot in 1968 and in 1969. As the kernel weight increased the number of kernels produced decreased. However, the increase in kernel weight had a greater effect on yield than the decrease in kernel number. In 1969, the authors found a highly significant negative correlation for the number of kernels per spike with the number of spikes per plot. Fonseca and Patterson (1968) also reported significant negative correlations between spikes per plot and kernels per spike. Normally, the number of kernels per spike is considered to be very sensitive to environmental factors such as drought. Therefore, the more spikes per plot, the less kernels per spike produced if there is environmental stress. Yield per plot was correlated but not significantly with kernels per spike, spikes per plot and kernels per plot.

Waldron (1929) found significant positive correlations at one of two environments between yield and kernels per head and yield and kernel weight. Similar results were found at the second environment with the exception of negative but nonsignificant correlations between yield and number of kernels per head.

Sprague (1926) found positive correlations of intermediate values between grain yield per spike, grains per spike and weight per grain. He reported very low correlation values between weight per kernel and grains per spike. Nebraska 60, one of the cultivars studied by Sprague, gave high positive correlations for grain yield per unit area with average number of spikes per unit area; intermediate correlation values with grain yield per spike and with weight per kernel; and low positive correlation with culm length.

In correlating parents and F_1; parents, F_1 and F_2; F_1 only; and F_2 only; Fonseca and Patterson (1968) had two relationships that were reversed from one year to the next. The number of spikes with kernel weight was negatively correlated and number of spikes with earliness was significantly negatively correlated one year and both were positively correlated the next year. Tall cultivars were found to flower later than short ones.

High positive correlations were reported by Roberts (1912) between number of culms per plant and weight of grain per spike and low positive correlations between culm length and number of grains per spike. He also found a high positive correlation between culm length and number of grains per spike. Roberts postulated that tillering is the most important vegetative phenomenon in the growth of the wheat plant as far as yield is concerned since it is very highly correlated with weight of grain per spike. Research by Arny and Garber (1918) strengthened Roberts' hypothesis. They found yield to have a fairly consistent correlation with average weight of kernels and average height of culms and somewhat higher correlation with number of culms.

Using four durum wheat crosses, Lebsock and Amaya (1969) determined correlation coefficients from F_2 plants and from combined F_3 and F_4 populations. Height was significantly correlated to kernel weight and yield in all crosses and with test weight in two crosses using F_2 plants. Kernel weight and test weight were associated in all crosses. Kernel weight was significantly related with yield in all four crosses. Maturity was positive and significantly associated with height in three of the four crosses. Positive and significant correlations occurred in the combined F_3 and F_4 populations for yield with kernel weight, with test weight and tiller number and for kernel weight with test weight. The number of kernels per spike was negatively correlated with kernel weight and test weight in three of the crosses and with the number of tillers in one cross. Height was significantly positively correlated with kernel weight; test weight, and maturity in two crosses and to yield in only one. Maturity was unrelated to yield and kernel weight in all crosses. Maturity was positive and significantly correlated to test weight in only one cross. Selection of early, short plants from this material might result in lines with lower kernel number and test weight.

Goulden and Elder (1926) obtained significant negative correlation between yield and susceptibility to leaf rust. Early heading varieties yielded higher than those heading late.

Seven oat populations were studied by Frey and Huang (1969). From these populations it appeared that the relationship between grain weight and 100-seed weight was curvilinear. Maximum yield was obtained when 100-seed weights were between 2.75 and 3.10 grams. One-hundred-seed weights greater than 3.10 grams decreased yield.

Investigators doing research on cereal grains have reported many different associations between grain yield and seed weight. If small segments of the total range of 100-seed weights were studied; positive, zero, or negative associations would be expected depending upon whether low, medium or high seed weights were used, respectively. Possibly this explains the variances in the relationship reported between these two traits.

METHODS AND MATERIALS

The material in this study consisted of selections from the wheat cross of Apache and Shawnee. Twenty heavy-kernel (Class I) and 20 light-kernel lines (Class III) were selected from 537 F_2 progeny in 1970. These lines, along with the parents plus the original bulk, a small-seeded bulk and a large-seeded bulk were grown in replicated 4-row plots in 1971. The plots were replicated three times at both the North Agronomy Farm of the Kansas Agricultural Experiment Station, Manhattan, Kansas and at the South Central Kansas Experiment Field, Hutchinson, Kansas.

Fifteen of the heaviest kernel lines and fifteen of the lightest kernel lines were selected from the material grown in 1971 and studied in 1972. Fifteen average-weight-kernel lines (Class II) (near the mid-parent) were also selected from the original 537 F_2 progeny lines and studied in 1972. The original bulk, a small-seeded bulk, and a large-seeded bulk, obtained by screening the material; and the parents were included in the study. In 1972, the plots were replicated three times at the Ashland Farm of the Kansas Agricultural Experiment Station, Manhattan, Kansas and at the South Central Kansas Experiment Field, Hutchinson, Kansas.

The plots, 4-meters long with rows spaced 30.5-centimeters apart, were planted in a randomized complete-block design. Plots were seeded at the rate of 300 kernels per row at Hutchinson and 375 kernels per row at Manhattan for both years. Preplant fertilizer was applied at the rate of 35 pounds of nitrogen per acre for 1971 and 1972 at Manhattan and 8 pounds of nitrogen and 5.5 pounds of phosphorous per acre for 1971 and 1972 at Hutchinson.

The plots at Manhattan in 1971 were planted on a Reading silt-loam soil and a Wymore silty-clay-loam soil. In 1972, the soil at Manhattan was a Reading silt loam. The soil at Hutchinson for 1971 and 1972 was a Clark loam or a Clark clay loam.

Measurement Procedures

Yield components (kernels per spike, spikes per unit area and kernel weight): Yield, maturity, height, and leaf rust measurements were taken on all plots in 1971 and 1972. In 1971 there was a natural Hessian fly infestation at Hutchinson so readings were taken. Hessian fly readings for 1972 were obtained from a greenhouse test.

Spikes Per Unit Area. Spikes per unit area were the total number of tiller bearing spikes in a 62.0-centimeter-section of one of the center rows of the plot.

Kernels Per Spike. Kernels per spike were the average number of kernels produced on ten spikes. The kernels from these 10 spikes were used to obtain average kernel weight.

Average Weight Per Kernel. Average weight per kernel was computed from the total number of kernels from 10 spikes and total weight of the kernels from the 10 spikes.

Yield. Yield was the weight in grams of grain produced by a 2.9-meter section of the two center rows.

Kernels Per Plot. Kernels per plot were calculated using yield and average kernel weight.

Plant Height. Plant height was measured in inches (later converted to centimeters) from the base of the culm to the tip of the spike (awns excluded) of three randomly selected culms at each of three locations within the center two rows of each plot.

Test Weight. Test weight in pounds per bushel (later converted to kg/hl) was taken on a composite sample from each entry at each location in replication two and three.

Maturity. Maturity was taken as the date that fifty per cent of the spikelets in a plot were in bloom. This was later calculated to the number of days after May 1.

Hessian Fly. In 1971, the Hessian fly infestation was calculated as the per cent of 50 tillers selected at random from each plot that were infected with "flax seeds". In 1972, greenhouse tests were conducted in the same manner.

Leaf Rust. Per cent susceptibility to leaf rust was determined by the number and size of the uredia. The USDA "Scale for Estimating Rust", found in "USDA, Agricultural Research Service, Field Notebook, Agronomic Notes", was used in determining the percentage.

Statistical Treatment of Data

A split plot analysis of variance was performed on the data on an IBM 360 Computer, at the Computing Center, Kansas State University. All correlation coefficients were calculated by the IBM 360 Computer at the Computing Center.

Climatological Data

Precipitation and temperature data for the period September through August for the years 1970-1971 and 1971-1972 for Manhattan are shown in

Table 1. These data are for the City of Manhattan, but are comparable to data recorded on the Agronomy Farm. Table 2 contains precipitation and temperature data for the same period at the South Central Kansas Experiment Field, Hutchinson, Kansas. Departures from the normal were not reported for Hutchinson.

Weather conditions at Manhattan for September 1970 to June 1971 were satisfactory with adequate precipitation and temperature for plant growth and development. The period of September 1971 to June 1972 started with a moisture deficit. The plots were planted the second of October in a very dry seed bed. Uneven germination resulted. On October 18, Manhattan received 1.5 inches of rain. After this moisture, fairly uniform stands developed. Above normal moisture was received during October and November, but the rest of the growing year had below normal precipitation. Temperature during this year was about normal.

Weather conditions at Hutchinson for September 1970 to June 1972 were satisfactory with adequate precipitation and temperature for wheat development.

Table 1. Precipitation, and maximum mean, minimum mean, and average air temperature from September through August for the years 1970-1971 and 1971-1972, Manhattan, Kansas

Month	Year	Precipitation (inches)		Temperature (F)			
		Total	Departure From Normal	Max. Mean	Min. Mean	Mean	Departure From Normal
September	1970	8.69	4.98	79.9	58.1	69.0	-1.6
	1971	1.18	-2.53	82.5	59.0	70.8	0.2
October	1970	2.75	0.43	64.2	44.3	54.3	-4.8
	1971	6.14	3.82	73.9	49.6	61.8	2.7
November	1970	0.78	-0.46	51.7	31.7	41.7	-1.6
	1971	4.01	2.77	54.9	35.1	45.0	1.7
December	1970	0.27	-0.67	46.8	25.3	36.1	2.5
	1971	0.16	-0.78	42.4	27.4	34.9	1.3
January	1971	0.75	-0.11	34.9	15.2	25.1	-4.5
	1972	0.41	-0.45	37.9	17.3	27.6	-2.0
February	1971	2.18	1.22	37.9	19.4	28.7	-5.1
	1972	0.30	-0.66	46.5	20.9	33.7	-0.1
March	1971	0.82	-0.89	53.3	30.4	41.9	-0.6
	1972	1.63	-0.08	61.5	35.2	48.4	5.9
April	1971	2.07	-0.53	70.4	44.7	57.6	2.3
	1972	2.27	-0.33	67.2	43.5	55.4	0.1
May	1971	5.56	1.19	74.9	51.1	63.0	-2.0
	1972	3.02	-1.35	75.0	53.1	64.1	-0.9
June	1971	4.37	-0.74	89.0	68.1	78.6	3.2
	1972	3.00	-2.11	88.7	63.4	76.1	0.7
July	1971	8.10	4.10	86.6	64.6	75.6	-5.1
	1972	3.26	-0.74	88.2	67.7	78.0	-2.4
August	1971	Trace	-4.18	88.6	64.9	76.8	-2.9

Data taken from climatological data for Manhattan, Kansas, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

Table 2. Precipitation, and maximum mean, minimum mean, and average air temperature from September through August for the years 1970-1971 and 1971-1972, Hutchinson, Kansas

Month	Precipitation (inches)		Temperature (F)		
	Year	Total	Max. Mean	Min. Mean	Mean
September	1970	5.93	83.0	57.0	70.0
	1971	1.93	84.0	57.3	70.7
October	1970	2.00	65.0	43.7	55.0
	1971	4.53	75.2	49.4	62.3
November	1970	0.15	53.8	30.7	42.3
	1971	2.21	55.1	34.9	45.0
December	1970	0.15	50.7	24.3	37.5
	1971	0.29	44.2	28.1	36.2
January	1971	0.86	39.7	17.5	28.6
	1972	0.18	41.8	17.5	29.7
February	1971	2.89	38.9	19.4	29.2
	1972	0.28	50.5	22.0	36.3
March	1971	0.17	56.9	30.6	43.8
	1972	0.84	66.9	34.7	50.8
April	1971	0.95	72.0	43.6	57.8
	1972	1.24	71.2	42.4	56.8
May	1971	3.05	75.2	52.7	69.9
	1972	3.81	76.5	51.8	64.2
June	1971	2.13	86.3	70.8	78.6
	1972	4.34	89.3	61.5	75.4
July	1971	5.00	91.5	66.1	78.8
	1972	2.95	90.3	64.5	77.4
August	1971	1.09	90.5	62.9	76.7

Data taken from climatological data for Experiment Field, Hutchinson, Kansas, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service.

RESULTS

Differences Between Means

Heavy-kernel-weight classes were all significantly greater in kernel weight than the light-kernel-weight classes in 1971 (Table 3 for Manhattan and Table 4 for Hutchinson) and in 1972 the heavy-kernel-weight class was consistently greater in kernel weight than the mid-parent value class which was also significantly greater in kernel weight than the light-kernel-weight class (Table 5 for Manhattan and Table 6 for Hutchinson). At Manhattan and Hutchinson, during both years, the kernel weight of the bulks was similar and near the mid-parent value. There does not seem to be any apparent trend at the different locations between the kernel weight of the parents or among the kernel-weight classes.

The parents out yielded both kernel-weight classes, which were the same, at Manhattan in 1971, but the bulks did not. The heavy-kernel-weight lines out yielded the light-kernel-weight lines at Hutchinson in 1971 but were similar to Shawnee. Apache was similar to Class III. During 1972, Classes I and II out yielded Class III at both locations. All the bulks yielded more than the kernel-weight classes at Manhattan in 1972 but only the large- and small-seeded bulks yielded more than the kernel-weight classes at Hutchinson.

Class III produced the most spikes per plot at Manhattan in 1971 and at Hutchinson in 1972. At the other two locations, the seed-weight classes did not differ in the number of spikes per plot. Generally, Shawnee produced more spikes per plot than Apache. The trends between the kernel-weight classes and the bulks were similar at Manhattan in 1971 and 1972. At Hutchinson, the spike producing trends between the kernel-weight classes were the opposite as

Table 3. Means for yield components, yield, test weight, half-bloom, height, and leaf rust in two kernel-weight classes and three bulks and parents as comparison, Manhattan, Kansas, 1971

Kernel Weight Class	Spikes Per Plot	Kernels Per Spike	Average Kernel Wt. (mg)	Kernels Per Plot (1,000's)	Yield (g/plot)	Test Weight (kg/hl)	Half-bloom	Height (cm)	Leaf Rust (%)
I	938.7	24.2	37.9	14.2	555.6	75.3	17.6	92.0	38.5
III	1023.5	25.4	33.3	15.9	539.2	74.7	21.9	98.0	39.9
LSD .05	55.8	.9	.5	.6	18.7	.4	.8	2.0	2.9
LSD .01	74.2	1.2	.7	.8	24.9	.6	1.0	2.7	3.9
Large Bulk	928.0	25.6	35.5	14.8	552.8	75.0	18.0	95.0	41.7
Original Bulk	1081.7	23.6	36.0	13.9	525.9	74.9	17.0	95.0	31.7
Small Bulk	1004.7	23.0	35.8	13.7	514.1	74.7	18.0	95.0	36.7
Apache	956.7	26.4	37.3	16.3	605.4	76.0	19.3	95.7	40.0
Shawnee	1033.7	23.0	33.1	15.8	587.9	76.1	19.3	93.3	40.0
LSD .05	62.7	1.0	.6	.7	20.6	.3	.5	1.3	2.9

Table 4. Means for yield components, yield, test weight, height and Hessian fly in two kernel-weight classes and three bulks and parents as comparison, Hutchinson, Kansas, 1971

Kernel Weight Class	Spikes Per Plot	Kernels Per Spike	Average Kernel Weight (mg)	Kernels Per Plot (1,000's)	Yield (g/plot)	Test Weight (kg/hl)	Height (cm)	Hessian Fly†
I	830.8	22.4	36.7	12.1	440.0	77.3	84.5	24.3
III	845.7	25.4	31.9	12.6	405.1	77.0	83.2	25.3
LSD .05	55.8	.9	.5	.6	18.7	.4	2.0	9.9
LSD .01	74.2	1.2	.7	.8	24.9	.6	2.7	12.1
Large Bulk	889.3	21.4	35.1	11.8	410.9	78.1	83.0	30.8
Original Bulk	835.0	25.4	34.8	12.2	423.6	78.3	84.3	20.2
Small Bulk	691.0	28.2	33.9	12.3	417.3	77.0	85.0	34.6
Apache	819.0	22.8	37.9	10.3	393.3	77.9	82.5	54.0
Shawnee	1043.3	24.4	30.5	15.0	458.9	76.7	87.5	.7
LSD .05	62.7	1.0	.6	.7	20.6	.3	1.3	9.9

†Average percentage of infested tillers

Table 5. Means for yield components, yield, test weight, half-bloom, height, and leaf rust in three kernel-weight classes and three bulks and parents as comparison, Manhattan, Kansas, 1972

Kernel Weight Class	Spikes Per Plot	Kernels Per Spike	Average Kernel Wt. (mg)	Kernels Per Plot (1,000's)	Yield (g/plot)	Test Weight (kg/hl)	Half-bloom	Height (cm)	Leaf Rust (%)
I	1364.4	14.2	32.5	16.5	531.8	81.0	17.5	113.9	41.6
II	1303.7	16.7	27.9	19.2	531.2	79.1	19.5	119.5	33.1
III	1372.6	17.9	23.9	20.4	482.8	77.9	21.3	115.7	25.3
LSD .05	83.4	.9	.9	.9	22.3	.4	.5	2.4	4.9
LSD .01	112.2	1.2	1.3	1.3	30.0	.5	.7	3.2	6.7
Large Bulk	1368.0	16.1	29.8	21.0	610.7	80.8	17.3	118.3	36.7
Original Bulk	1494.6	17.7	30.2	19.2	578.8	79.9	18.7	116.7	40.0
Small Bulk	1587.3	16.4	29.6	20.3	602.1	80.3	18.3	115.0	40.0
Apache	1556.7	14.4	32.5	15.0	490.2	81.3	19.0	111.7	40.0
Shawnee	1593.7	14.4	27.5	19.3	529.1	81.3	20.0	116.0	36.7
LSD .05	80.4	.8	.9	8.6	21.2	.1	.3	.9	4.9

Table 6. Means for yield components, yield, test weight, height, and Hessian fly in three kernel-weight classes and three bulks and parents as comparison, Hutchinson, Kansas, 1972

Kernel Weight Class	Spikes Per Plot	Kernels Per Spike	Average Kernel Weight (mg)	Kernels Per Plot (1,000's)	Yield (g/plot)	Test Weight (kg/hl)	Height (cm)	Hessian Fly†
I	1184.0	17.4	30.9	15.3	472.1	78.2	95.5	68.4
II	1248.0	17.9	27.1	17.5	470.8	77.4	102.6	65.9
III	1333.7	18.8	23.3	18.9	438.7	76.4	103.4	43.8
LSD .05	83.4	.9	.9	.9	22.3	.4	2.4	25.8
LSD .01	112.2	1.2	1.3	1.3	30.0	.5	3.2	34.8
Large Bulk	1386.0	16.4	28.1	17.7	496.5	77.8	95.0	57.0
Original Bulk	1327.7	17.8	27.1	17.3	468.2	77.4	103.7	50.0
Small Bulk	1287.3	19.1	27.0	18.0	483.2	77.7	102.0	59.5
Apache	1246.3	18.7	29.9	18.9	563.0	79.6	100.0	100.0
Shawnee	1377.3	19.6	24.3	23.1	454.2	77.8	101.0	33.0
LSD .05	80.4	.8	.9	8.6	21.2	.1	.9	25.8

†Average percentage of infested tillers

the spike producing trends of the bulks.

Spikes that produced the most kernels occurred in Class III at all four locations. The small-seeded bulk produced more kernels per spike than the other bulks at Hutchinson only. At Manhattan in 1971, the large-seeded bulk produced the greatest number of kernels per spike and in 1972 the original bulk produced the most. Shawnee either produced more kernels per spike than Apache or was equal to Apache except at Manhattan in 1971, where Apache produced more kernels per spike than Shawnee. Shawnee's production of kernels per spike, for both years at Hutchinson, did not significantly differ from that of Class III.

The number of kernels per plot followed the same trend as kernels per spike. Kernels per plot, determined by yield per plot and kernel weight, was greatest in Class III at three locations as expected, and equal to Class I at the other. The lighter the kernel, the more kernels that are needed to produce the same yield as heavy-kerneled lines.

Generally, test weight was heaviest in Class I with the two classes at Hutchinson in 1971 not being significantly different. Apache tended to be heavier than all lines at all locations while Shawnee varied from heavier than all lines at Manhattan in 1971 and 1972, to equal to Class III at Hutchinson in 1971, to greater than Classes II and III and less than Class I at Hutchinson in 1972.

The heavy-kernel lines flowered earlier than the light-kernel lines.

In 1971, both classes seemed equally susceptible to leaf rust. The trend was not the same in 1972. Class I was definitely more susceptible, while Class III was the least susceptible.

Hessian fly resistance was not associated with any of the yield components.

Correlations

Simple correlation coefficients between kernel weight and other characters studied in 1971 and 1972 are given in Table 7. A trend is not evident between kernel weight and spikes per plot but the significant correlations that did occur were negative. Kernels per spike shows a negative trend to kernel weight but none of the correlations are significant. Correlation coefficients of kernels per plot and kernel weight were negative and significant at either the 5% or 1% level for all kernel-weight classes and for both years. Yield of Class III at Hutchinson and Class II at Manhattan in 1972 had a positive association with kernel weight while yield of Class I at Hutchinson had a significant negative correlation. Test weight was positively associated with kernel weight in Classes II and III at Manhattan in 1971 and Class II at Manhattan in 1972, but Class III at Hutchinson in 1971 was significant and negatively correlated with kernel weight. Height showed little association with kernel weight except for a negative significant correlation in Class III at Manhattan in 1971. A significant inverse relationship occurred between half-bloom and kernel weight in all but one class. Neither leaf rust nor Hessian fly showed any relationship with kernel weight.

Correlation coefficients for all variables studied except kernel weight are given in Tables 8, 9, 10, and 11 for Manhattan, 1971; Hutchinson, 1971; Manhattan, 1972; and Hutchinson, 1972, respectively. Yield was found to be positively associated with kernels per plot at all locations and in all kernel-weight classes. Yield was also positively associated with spikes per plot in Class I at three of four locations. Early flowering lines yielded more than late flowering lines causing a negative trend between yield and half-bloom in Class III at Manhattan in 1971 and in Classes II

Table 7. Simple correlation coefficients between kernel weight and yield components, yield, test weight, height, half-bloom, leaf rust and Hessian fly with regard to kernel-weight class, 1971 and 1972

	Kernel Weight Class	Spikes Per Plot†	Kernels Per Spike†	Kernels Per Plot†	Yield†	Test Weight‡	Height†	Half-bloom†	Leaf Rust‡	Hessian Fly‡
Manhattan 1971	I	.016	-.249	-.269*	.109	-.348	.050	-.292*	-.307	
	III	-.135	-.150	-.373**	.110	-.612**	-.366**	-.309*	.386	
Hutchinson 1971	I	-.359**	-.174	-.325*	.047	-.146	-.220			.284
	III	.000	-.190	-.305*	.021	.126	-.107			-.230
Manhattan 1972	I	-.124	.122	-.358*	.223	.368	.064	-.259	.093	
	II	.118	-.113	-.618**	.291	.561*	.025	-.593**	.679**	
	III	.237	-.162	-.480**	.447**	.646**	-.020	-.377*	.101	
Hutchinson 1972	I	-.286	-.179	-.745**	-.373*	.392	.204			-.156
	II	-.541**	-.050	-.357*	.392**	.677**	-.190			-.049
	III	-.454**	-.017	-.503**	.238	.294	-.129			.129

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

†-degrees of freedom for 1971=48; 1972=43
‡-degrees of freedom for 1971=18; 1972=13

Table 8. Simple correlation coefficients among all pairs of variables studied, except kernel weight, in two kernel-weight classes, Manhattan, Kansas, 1971

	Kernel Weight Class	Kernels Per Spike†	Kernels Per Plot†	Yield†	Test Weight‡	Height†	Half-bloom†	Leaf Rust‡
Spikes Per Plot	I	-.284*	.330*	.320*	.280	.132	-.138	-.123
	III	-.266*	.234	.188	.000	.026	.029	-.310
Kernels Per Spike	I		.237	.184	.197	-.011	.226	.186
	III		.245	.276*	.213	.237	.127	.367
Kernels Per Plot	I			.796**	.506*	.262*	.297*	-.217
	III			.712**	.176	.167	-.086	.037
Yield	I				.371	.247	.221	-.295
	III				-.253	-.035	-.327*	.314
Test Weight	I					.224	.077	.064
	III					.377**	.251	-.046
Height	I						.076	.355
	III						.613**	-.002
Half-bloom	I							-.257
	III							-.103

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

†-degrees of freedom=58
‡-degrees of freedom=18

Table 9. Simple correlation coefficients among all pairs of variables studied, except kernel weight, in two kernel-weight classes, Hutchinson, Kansas, 1971

	Kernel Weight Class	Kernels Per Spike†	Kernels Per Plot†	Yield†	Test Weight‡	Height†	Hessian Fly‡
Spikes Per Plot	I	-.471**	.532**	.406**	.155	.176	-.346
	III	-.518**	.255*	.297*	-.188	.396**	-.460*
Kernels Per Spike	I		-.001	-.058	-.140	.095	.277
	III		.185	.074	-.008	.117	.372
Kernels Per Plot	I			.926**	-.087	.344**	-.172
	III			.875**	.155	.539**	.294
Yield	I				-.150	.298*	-.015
	III				.175	.469**	.051
Test Weight	I					.428**	.087
	III					-.027	-.057
Height	I						.161
	III						.076

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

†-degrees of freedom=58
‡-degrees of freedom=18

Table 10. Simple correlation coefficients among all pairs of variables studied, except kernel weight, in three kernel-weight classes, Manhattan, Kansas, 1972

	Kernel Weight Class	Kernels Per Spike†	Kernels Per Plot†	Yield†	Test Weight‡	Height†	Half-bloom †	Leaf Rust‡
Spikes Per Plot	I	.190	.411**	.352*	-.306	.321*	.155	-.338
	II	.072	.041	.202	-.371	-.261	-.034	-.319
	III	-.072	.113	.367*	.415	-.004	-.016	-.267
Kernels Per Spike	I		.206	.305*	.125	-.009	-.132	-.445
	II		.151	.069	-.205	-.139	.202	.030
	III		-.014	-.120	-.516*	.084	.211	.012
Kernels Per Plot	I			.824**	-.571*	.259	.057	-.455
	II			.562**	-.217	.244	.244	-.361
	III			.562**	-.398	-.099	-.092	.370
Yield	I				-.339	.285	-.107	-.525*
	II				.216	-.268	-.323*	.654**
	III				.192	.093	-.406**	.541*
Test Weight	I					-.372*	-.422**	-.055
	II					-.258	-.741**	.623*
	III					-.413**	-.199	-.058
Height	I						.037	-.290
	II						.242	-.265
	III						.065	-.263
Half-bloom	I							.555*
	II							-.671**
	III							-.432

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

†-degrees of freedom=43
‡-degrees of freedom=13

Table 11. Simple correlation coefficients among all pairs of variables studied, except kernel weight, in three kernel-weight classes, Hutchinson, Kansas, 1972

	Kernel Weight Class	Kernels Per Spike†	Kernels Per Plot†	Yield†	Test Weight‡	Height†	Hessian Fly‡
Spikes Per Plot	I	-.186	.161	.039	.175	-.222	.082
	II	-.033	.335*	-.064	-.382	.128	-.160
	III	-.146	.173	-.181	-.137	-.122	.066
Kernels Per Spike	I		.250	.209	-.342	.045	.558*
	II		.233	.212	-.057	-.310*	.226
	III		.073	.103	-.142	.236	-.011
Kernels Per Plot	I			.894**	-.212	-.032	.479
	II			.716**	-.110	.097	.280
	III			.714**	-.388	.190	-.139
Yield	I				.009	.064	.507
	II				.434	-.069	.217
	III				-.231	.147	-.033
Test Weight	I					-.211	-.239
	II					-.228	-.248
	III					-.310*	-.191
Height	I						.038
	II						.049
	III						-.173

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

†-degrees of freedom=43
‡-degrees of freedom=13

and III at Manhattan in 1972. Yield increased as leaf rust decreased in Class I at Manhattan in 1972 but in Classes II and III at the same location yield increased when leaf rust susceptibility increased.

Spikes per plot was significantly negatively correlated with kernels per spike in both classes at Manhattan and Hutchinson in 1971 but this did not occur in 1972. There was a significant positive association between spikes per plot, and kernels per plot and yield, at both locations in 1971 and at Manhattan in 1972.

Test weight was significantly positively correlated with kernels per plot at Manhattan in 1971 and significantly negatively correlated with kernels per plot at Manhattan in 1972. At Hutchinson, the relationship was nonsignificant.

Height and half-bloom were correlated with kernels per plot in Class I, in 1971, but this trend did not follow in 1972. Height was positively correlated with test weight in Class III at Manhattan and Class I at Hutchinson in 1971 and negatively correlated with both classes in 1972.

All other correlations were independent of each other or showed no trend from one location to the next.

When correlations were calculated over all entries at a location, instead of kernel-weight classes, a definite negative trend among yield components occurred (Table 12). This trend does not hold for relationships between yield and yield components.

Table 12. Simple correlation coefficients among yield components and between yield components and yield with regard to location

	r_{xy}	r_{xz}	r_{yz}	r_{xw}	r_{yw}	r_{zw}
Manhattan 1971†	-.250**	-.205*	-.273**	.208*	.153	.163
Hutchinson 1971†	-.401**	-.179*	-.437**	.353**	-.097	.163
Manhattan 1972‡	.061	.095	-.341**	.288**	.032	.402
Hutchinson 1972‡	-.036	-.469**	-.239**	-.103	.092	.264

x=spikes per plot; y=kernels per spike; z=kernel weight; w=yield

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

†-degrees of freedom=58
‡-degrees of freedom=43

DISCUSSION

Yield is the economic end product of winter-wheat's plant life cycle and may be represented as a rectangular parallelopiped of the three yield components, x, spikes per unit area; y, kernels per spike; and z, kernel weight. These components develop in a sequential manner during the growing season. Winter wheat is planted from early September to mid-October in Kansas and matures the following June or early July.

Tiller initiation occurs in October and November and in February and March if enough moisture is present. Culm elongation takes place from early April to early May and spike formation takes place the latter part of April. Fertilization occurs during the first to third weeks of May. Kernel filling and ripening follow during the month of June. Tiller initiation has an effect on the events taking place during spike formation, and the events during tiller initiation and spike formation have an effect on seed development. This relationship is the result of both internal and external stresses and results in an oscillatory pattern of the yield components. As one component over produces due to an advantageous environment, the next component may produce less than average. This is known as component compensation as proposed by Adams (1967).

Differences Between Means

As the data means show, more spikes per plot were produced in 1972 than 1971. This follows closely to the precipitation pattern. Tables 1 and 2 show that for the months of October, November, February and March, much more total precipitation fell in 1972 than in 1971.

On the other hand, the means for kernels per spike were higher in 1971 than 1972. Moisture preceding and during spikelet formation (March and April) was low as depicted by the departure from the precipitation normal in Table 1. This deficit was not crucial but did put more strain on the plants in 1972 due to the added spikes that were developing spikelets. Baier et al. (1967) also found that high moisture between jointing and heading favored an increase in number of kernels per spike. Direct evidence is not available to show that less spikelets developed in 1972 because spikelets per spike were not measured, but the means show there were fewer kernels per spike. Fewer kernels per spike may have also been caused by the sequential trait of fertilization and kernel filling. Under adverse growing conditions, the last spikelets or florets to be differentiated will have the least chance of producing seed (Bonnett, 1966). In 1972, environmental conditions during anthesis were not as favorable for kernel production as in 1971.

Kernel-weight means were larger in 1971 than in 1972. More precipitation occurred in 1971 than in 1972. This along with the fact that there were less tillers in 1971, allowed the plant to produce fewer but heavier kernels. High moisture conditions between soft-dough and ripening favors wheat-kernel weight (Baier et al., 1967).

Yield means were erratic. At Manhattan, yield means were greater in 1971, but at Hutchinson, yield means were greater in 1972. A severe reduction in the means of kernels per spike at Manhattan in 1972, possibly caused by too many tillers for environmental conditions at spike differentiation, may have caused the reduction in the yield means. Quisenberry (1928) and Kronstad and Foote (1964) concluded that kernels per spike have the greatest effect on yield. But this does not seem to be the case in this study. The means for kernels per plot were greater in 1972 than in 1971 meaning the factor that influenced yield was kernel weight. At Hutchinson, the yield means were greater in 1972 due to the greater tiller or spike number. This follows work done by Leisle (1972) with spring wheat at Manitoba that showed tillering influenced yield.

Kernel-weight means were significantly different between all kernel-weight classes at all locations. There were no differences in test weight means between the kernel-weight classes in 1971 but in 1972 there were significant differences. Yamazaki and Briggle (1969) would explain these differences by what they call packing efficiency; the percent of bulk volume occupied by the grain. Grain shape and surface characteristics such as humping, dorsal or lateral depression and wrinkling affect random packing efficiency. Broken, split, or flattened kernels also reduce packing efficiency. They also found the higher the test weight the better the packing efficiency.

Heavy-kernel lines flowered earlier than light-kernel lines, allowing more time for carbohydrates to translocate from the culm to the kernel.

Leaf rust and Hessian fly infections did not vary among kernel-weight classes. This showed that inheritance for resistance or susceptibility was not related to kernel weight.

Correlations

Correlation coefficients between kernel weight and spikes per plot were significantly negatively correlated in Class I at Hutchinson in 1971 and in Class II and Class III at Hutchinson in 1972 (Table 7). As the number of spikes per plot increased in each kernel-weight class the average kernel weight decreased. Less seed was planted at Hutchinson, because Hutchinson does not receive as much annual precipitation as Manhattan, but more tillers developed per seed planted at Hutchinson than at Manhattan. The environmental conditions at Hutchinson stressed the plants after tiller development causing negative associations between spikes per plot and kernel weight. Continued environmental stress after culm elongation would reduce kernel size or kernel number depending on when the stress occurred (Laude, 1938). All other coefficients between kernel weight and spikes per plot were nonsignificant, with Class III at Hutchinson in 1971 being zero.

Kernels per spike showed negative trends with kernel weight but none of the correlations were significant. Kernels per plot were significantly negatively correlated in all kernel-weight classes. Determination of kernels per plot, by using yield and kernel weight explains the negative correlation that exists between kernel weight and kernels per plot. As kernel weight increased the number of seeds produced decreased.

Yield was significantly positively correlated to kernel weight in Class III at Manhattan in 1972 and in Class II at Hutchinson in 1972. Class I at Hutchinson in 1972 was significantly negatively correlated to yield. Knott and Talukdar (1971) found similar positive correlations between kernel weight and yield. On the other hand, Frey and Huang (1969) found that 100-seed weights of oats above 3.10 grams, decreased yield. As kernel weight increased, kernels per spike declined and especially kernels per plot decreased significantly. Increased kernel weight could not over come this decrease.

Test weights were significantly positively correlated in three classes and significantly negatively correlated in one (Table 7). These negative correlations gave some indication of the stress the plant apparently was in after anthesis. The number of spikes per plot and number of kernels per spike were too great for the plant to completely fill all the kernels, consequently the lower test weight with increase in kernel weight.

Height, leaf rust and Hessian fly showed no apparent associations with kernel-weight classes.

Half-bloom was significantly negatively correlated with kernel weight in four of five kernel-weight classes, meaning that the earlier the lines flowered the heavier the kernels that developed. This may be due to more time for berry filling assuming early flowering lines have more time to reach physiologic maturity than late flowering lines.

Correlation coefficients among pairs of variables studied other than kernel weight showed spikes per plot to be significantly negatively correlated to kernels per spike in both classes in 1971 and nonsignificant in 1972 (Tables 8-11). The low number of spikes per plot in 1971 were compensated for with more kernels per spike, whereas in 1972, there was no association between kernels per spike and spikes per plot.

Spikes per plot were significantly positively correlated to kernels per plot in Class I, three times; Class II, once; and Class III, once. Yield was significantly and positively correlated to spikes per plot in Class I, three times and twice, in Class III. Yield was also significantly correlated to kernels per plot in all classes at all locations. In these classes, the more spikes per plot the more kernels per plot and consequently a greater yield.

In Class III at Manhattan in 1971 and in Classes II and III at Manhattan in 1972, half-bloom was negatively correlated with yield. Also in Classes I and II at Manhattan in 1972, test weight was significantly negatively correlated with half-bloom. The earlier a line flowered the better the chance was of obtaining a larger kernel.

Leaf rust was significantly and positively correlated to yield in two classes and significant and negatively correlated to yield in one at Manhattan in 1972. The influence leaf rust has on yield depends on the stage of the plant at infection and degree of infection. A low infection may enhance yield but a high infection may be detrimental to yield.

Associations of test weight with height and kernels per plot showed no trend. Test weight with height had three classes significantly negatively correlated, two classes positively correlated and the rest nonsignificant. Association of test weight with kernels per plot had one class positively and one class negatively significantly correlated and the rest were nonsignificant. Yamazaki and Briggle (1969) explain these correlations on the basis of grain shape and surface characteristics, such as humping, or dorsal or lateral depressions causing variations in void-space ratio; hence directly effecting the random packing efficiency. Variations in density are due, at least in part to air spaces within the kernel.

Environment and genotype are largely responsible for correlations between yield components. Adams (1967) and Grafius (1972) postulated that component traits share a common environmental resource pool and competition among yield components for these resources leads to negative correlations. Table 12 supports this hypothesis. Negative correlations exist between yield components but are not present when these components are associated with yield.

SUMMARY AND CONCLUSIONS

Selection for kernel weight and its influence on yield and other yield components was studied in two kernel-weight classes in 1971 and three kernel-weight classes in 1972 in an Apache/Shawnee cross.

Between the two years, more spikes per plot were produced in 1972 than in 1971. The significant correlation coefficients of spikes per plot with kernel weight were negative. Class I at Hutchinson in 1971 and Classes II and III at Hutchinson in 1972 had significant correlations. The significant correlations all being at Hutchinson may be because more tillers developed per seed planted, thereby placing a greater stress on the plants at Hutchinson for the environmental conditions that prevailed.

Kernel weights were greater in 1971 than in 1972. Significant positive correlations existed between yield and kernel weight in Class III at Manhattan in 1972, and in Class II at Hutchinson in 1972. Significant negative correlation occurred in Class I at Hutchinson in 1972. The reduced number of kernels per spike in Class I at Hutchinson in 1972 apparently caused a reduced yield.

Kernels per spike were found to be nonsignificantly correlated with kernel weight in all classes. More kernels per spike were produced in 1971 than in 1972.

These data support the conclusion that varieties less prone to tillering supposedly would leave more environmental resources in a common pool from which kernels per spike and kernel weight could draw. The competition among yield components for environmental resources, called component compensation by Adams (1967), tends to produce an oscillatory pattern which causes negative associations among the yield components. The yield component most affected by the environment will depend on what component is developing at the time of environmental stress. This component compensation remains as one of the impediments to progress in selecting for a complex trait, such as yield.

Under Kansas conditions, it appears, varieties that produce an "average" number of tillers, under adverse and favorable conditions, with as many kernels per spike as possible and a kernel that is above "average" in weight but not extremely heavy should be grown.

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SELECTION FOR KERNEL WEIGHT AND ITS INFLUENCE ON YIELD AND YIELD COMPONENTS IN A SIMPLE WHEAT (*TRITICUM AESTIVUM* L.) CROSS

by

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The relation of yield and yield components to kernel weight in wheat was investigated in two kernel-weight classes in 1971 and three kernel-weight classes in 1972. This study was initiated to determine what weight of the wheat kernel would be best adapted to Kansas. The materials studied were lines and bulks from a single cross, 'Apache/Shawnee'. Forty lines, heavy- and light-kernel-weight classes, were studied in 1971 and forty-five lines, heavy, light, and lines around the mid-parent, were studied in 1972.

The components of yield studied were spikes per unit area, kernels per spike and average kernel weight. Other characters studied were kernels per plot, test weight, height, leaf rust, Hessian fly, and date of half-bloom.

Yield was obtained from the two center rows of a four row plot, each four-meters in length. Spikes per plot were determined by counting the number of tiller bearing spikes in a two-foot section of one of the two center rows. Ten heads selected at random from the two-foot section were used to determine average number of kernels per spike. The weight of the kernels from the ten heads and the number of kernels determined average kernel weight.

More spikes per plot were produced in 1972 than in 1971. The significant correlation coefficients of spikes per plot with kernel weight were negative. Class I at Hutchinson in 1971, and Classes II and III at Hutchinson in 1972 had significant correlations.

Kernel weight of the plots was greater in 1971 than in 1972. Significant positive correlation existed between yield and kernel weight in Class III at Manhattan in 1972, and in Class II at Hutchinson in 1972. Significant negative correlations occurred in Class I at Hutchinson in 1972.

More kernels per spike were produced in 1971 than in 1972. Kernels per spike, height, leaf rust and Hessian fly were not associated with kernel weight. Kernels per plot were found to be significant and negatively correlated to kernel weight in all classes. Half-bloom was also significant and negatively correlated to kernel weight in four of five classes. Test weight was positive and significantly correlated to kernel weight in three classes and negative and significantly correlated in one.

Correlations calculated for all entries at a location showed significant negative correlations among yield components.

The data support the conclusion that the components of yield compete for environment resources and the component most affected by the environment will depend on what component is developing at the time of environmental stress. Component compensation among yield components leads to negative correlations among them.

Under environmental conditions in Kansas, it appears, varieties that produce an "average" number of tillers, with as many kernels per spike as possible and a kernel that is above "average" in weight but not extremely heavy, should be grown.