YIELD AND PROTEIN RELATIONSHIPS AMONG F_4 LINES INVOLVING AN ATLAS 66 DERIVED HIGH PROTEIN PARENT

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CHAPTER I

INTRODUCTION

Protein is an important constituent of the daily principal foods of mankind. Wheat is one of the most important cereal food crops in the world. Wheat, together with rice, corn and sorghum, is used as a primary carbohydrate source in many countries. In general, however, these cereal grains are relatively low in protein content. The development and utilization of wheat with higher inherent protein levels could greatly improve the nutrition of peoples of the world. The quality and the quantity of grain proteins also are the major factors in determining the quality of wheat flour and its suitability for making bakery products. Protein content levels in wheat are influenced by genetic factors as well as by environmental factors, particularly, moisture and available nitrogen in the soil (19). Studies by numerous investigators have indicated that protein content is negatively associated with grain yield in wheat (3, 4, 6, 25). However, in case of yield and protein content, yield itself cannot be ignored in breeding efforts to improve protein content of wheat because the amount of protein available for food purposes is determined largely by the quantity of grain produced.

The primary objectives of this study were:

(a) to determine the relationship of protein content to grain yield and to determine the relationship of these two traits with other plant characters, and

(b) to determine if both high protein and high yield could be combined in the same genotype and to isolate such lines from the genetic population employed in this study.

CHAPTER II

LITERATURE REVIEW

Effect of Environmental Conditions and Nitrogen on Grain Protein Content

Numerous investigators have concluded that protein content in the grain of wheat and other cereal crop is controlled by a number of genes. However, it has been pointed out that a variety of wheat produces different percentages of grain protein when the variety is grown in different years or at different locations. Protein content in wheat is greatly influenced by environmental factors such as temperature, moisture, light intensity and light quality. Also, available soil nitrogen is another important factor affecting protein content in wheat.

Smika and Greb (23) studied the relationship of grain protein content of winter wheat to soil and climatic factors at three locations in the semiarid Central Great Plains. They found that protein content was negatively correlated ($r = -0.70$) with the total precipitation that occurred for a period of 15 days during the flowering period. Grain protein levels were found to be positively correlated ($r = 0.82$) with the total soil $NO_3 - N$ occurring to depths of 1.2 or 1.8 m.

Schlehuber and Tucker (21), reporting on experiments conducted at ten locations in Western Oklahoma, concluded that additions of nitrogen resulted in an increase in grain protein content of wheat grown on most soils. The protein content tended to be higher when wheat was grown in hot dry environments and lower when grown in cool moist environments. They explained that nitrogen content of the soil and the rate of nitrification were, in general, higher in dry environments than in humid environments.

Terman, et al. (26) found a highly significant inverse relationship between yield and protein content in hard red winter wheat at different levels of applied nitrogen in a study conducted over a three-year period. They concluded that the major effect of applied nitrogen was to increase total yield if water and other growth factors were adequate. An increase in grain protein occurred only when nitrogen was absorbed by the plant in excess of vegetative needs. Nitrogen application combined with severe water deficits resulted in an increase in grain protein content. However, in intermediate moisture conditions, nitrogen application increased both yield and protein content.

Johnson, et al. (11) studied two winter wheat varieties differing inherently in grain protein content in an experiment extending over a three-year period. The two varieties were 'C.I. 14016' and 'Lancer'. Generally, C.I. 14016 produced higher grain protein content than Lancer. They found that the grain protein responses of the two varieties to nitrogen fertilizer were clearly linear within the range of nitrogen applications utilized in the study. Furthermore, statistically significant yield responses to nitrogen fertilizer were found in six of ten trials involved in this study. However, the results indicated that no relationship between grain yield and grain protein content existed under the conditions of the study.

Haunold, et al. (9) studied the variation in the grain protein content of the soft winter wheat varieties 'Atlas 50' and 'Atlas 66', and the hard winter wheat varieties 'Comanche' and 'Wichita'. The results indicated that at a low level of soil nitrogen availability, grain protein was negatively correlated with yield in all varieties. They suggested that the protein in the grain resulted from the translocation of nitrogenous compounds from other parts of the plant. Moreover, the level of nitrogen in the plant presumably influences the amount translocated to the grain. The level of nitrogen in the wheat plant, in turn, is affected directly by the availability of nitrogen in the soil.

Ramón and Laird (19) studied the effects of soil moisture and nitrogen fertilizer on yield and protein content in wheat. They concluded that the percentage of protein in the grain increased as the availability of moisture decreased. The protein content of the grain was lowest in the wettest treatment and highest in the driest treatment.

Harper and Paulsen (8) studied the influence of intensity, quality, and duration of light on nitrogen reduction and assimilation in wheat. They found that high light intensity had no consistent effect on nitrate reductase activity in the leaf blades but increased soluble protein and decreased nitrate concentration. Blue light increased nitrate reductase activity and soluble protein but decreased nitrate content as compared to red light.

The Relationship of Grain Protein Content to Other Plant and Seed Characteristics

Many investigations have been conducted on the relationship between grain protein content and various plant and seed characters.

Characters studied have included number of tillers, grain yield, maturity, plant height, and other variables.

Clark (3), one of the earlier investigators, studied the relationship between yield and grain protein content of F_2 plants and F_3 lines of a cross between two wheat varieties, 'Marquis' and 'Hard Federation'. He found that the F_2 plants were intermediate with respect to the parents in crude protein content and also that the crude protein was negatively correlated with grain yield with a coefficient of correlation of -0.231 ± 0.027. In contrast, the crude protein of the F_3's was positively correlated with grain yield with a coefficient of correlation of 0.256 ± 0.042. He concluded that yield affected the protein content of the hybrids more than any other factors studied which included date of heading and ripening, fruiting period, and plant height.

Stuber, et al. (25) studied grain protein content and its relationship to other characters in populations derived from a cross of Wichita, a hard red winter wheat variety and Atlas 66, a soft red winter wheat variety. They found that all the phenotypic correlations between grain protein content and other characters studied in the F_2 generation were highly significant. Grain protein content was negatively correlated with plant height, number of tillers, grain yield per head, and grain yield per plant. Only one character, flowering date, was positively associated with grain protein content.

Davis, et al. (4) studied the phenotypic and genotypic correlations between protein and yield in four populations derived from soft red winter wheat crosses involving the high protein variety Atlas 66.

The results showed a general negative relationship between grain protein content and grain yield in three of the four crosses.

Duffield, et al. (6) conducted a field experiment to investigate the interrelationships and inheritance of nitrate reductase activity, grain protein and straw protein in the F_2 generation of a cross involving an Atlas 66 - derived high protein parent, 'NE 65679'. They found that grain protein, water soluble protein and nitrate content were positively correlated with the nitrate reductase activity. In this population, Duffield (5) found that grain protein content was negatively correlated with grain yield $(r = -0.267^{**})$.

Johnson, et al. (14) studied grain protein and grain yield relationships in the International Winter Wheat Performance Nurseries grown in 1969 and 1970. Results were obtained from tests conducted at 52 sites in 33 countries. Correlation coefficients between yield and protein content ranged from -0.43 to zero for Atlas 66 - derived high protein varieties. However, correlation coefficients between yield and protein content based on varieties not known to be genetically different in protein potential ranged from -0.61 to +0.65.

Recently, in a report of nitrate reductase activity and nitrogen translocation in conventional height and semidwarf spring wheat varieties, Edwards, et al. (7) found that grain yield and grain protein production (kg/ha) were positively correlated with nitrate reductase activity. It could be interpreted in this case that grain yield was positively associated with grain protein production (kg/ha).

Genetic Effects on Protein Content

Working with F_2 plants from a cross involving an Atlas 66 - derived high protein parent, Duffield, et al. (6) found that the heritability estimate for nitrate reductase activity was 71.7% and that heritability estimates for grain protein ranged from 30.3% to 75.5% with a mean of 44.0%. They also found that nitrate reductase activity was positively correlated with percent grain protein and percent water soluble protein with the pooled correlation coefficient of 0.402 and 0.353, respectively. Also, Rao and Croy (20) concluded that high nitrate reductase activity levels were correlated with high grain protein content in wheat. They found that the protease enzyme level was higher in wheat varieties having a high grain protein. More recently, Morris and Croy (16) reported that the pooled broad-sense heritability estimates for protease activity at pH 7 and for forage nitrogen in a wheat population were 0.638 and 0.665, respectively. The largest correlation among variables in their study was between forage nitrogen and grain protein, with a correlation coefficient of 0.358.

Worzella (27) in a two-year study on the inheritance of protein content among crosses of soft red winter wheat varieties found that the hybrids were intermediate to the parents in protein content. The data indicated that the mode of inheritance of protein content was conditioned by multiple factors. Haunold, et al. (10) found that the protein content distribution in F_2 plants and F_3 lines of crosses involving Atlas 66 resembled a normal distribution and gave no evidence of a preponderance of dominant genes for either high-or low-protein.

Genetic Effects on Grain Yield and Maturity

Bhatt (2) studied the inheritance of heading date, plant height, and kernel weight in two spring wheat crosses, 'Timgalen' x 'Sonora 64A' and Timgalen x 'Eagle'. He found that for heading date the F_1 means were intermediate between the two parental means, but were nearer to the early parent. This indicated partial dominance of genes controlling earliness in heading. Heading date was controlled primarily by additive genetic effects although partial dominance for heavy kernel weight was indicated.

Pinthus (18) studied the inheritance of spike initiation and heading date in crosses between early and late spring wheat varieties. He stated that the two characters were controlled by two gene pairs. One gene determined the time of spike initiation and another controlled the length of the period from spike initiation to heading. These two genes were found to be linked. However, he pointed out that early spike initiation was dominant to late initiation and that a short period from initiation to heading was dominant to a long period. Anwar and Chowdhry (1) also found that earliness of heading was controlled by partially dominant factors.

Johnson, et al. (12) studied the inheritance of seven plant and seed characters including maturity and grain yield in winter wheat populations developed from a cross of 'Seu Seun 27' by 'Blue Jacket'. They found that maturity was controlled by a single dominant gene pair and earliness was dominant over late maturity. The coefficient of heritability for maturity in the F_2 generation was high and indicated that selection in this generation would be effective. For grain yield, the heritability estimates were considered low. However, they found that the F_2's exhibited a bimodal frequency distribution for kernel weight which indicated the presence of relatively few genes. They pointed out that kernel weight and number of spikes per plant were important contributing factors in grain yield in the F_1 generation.

Effect of Translocation

Translocation of nitrogenous substances from vegetative parts to grain is an important physiological aspect in determining the quantity of protein in wheat grain. Edwards, et al. (7) found that translocation efficiency was positively correlated with grain protein production ($r = 0.725^{**}$) but not with percent protein, in an experiment on spring wheat varieties.

Mikesell and Paulsen (15) studied notrigen translocation in wheat and concluded that the translocation of C^{14} - labelled amino acids from the culms to the grain during grain development was low after anthesis, increased at mid-maturity and decreased slightly at full maturity. They also found that efficiency of translocation did not differ between low- and high-protein lines.

Johnson, et al. (13) concluded from their experiment that during the grain development period, nitrogen content in the grain of high protein lines was significantly higher than that of the low protein varieties. However, they stated that high protein wheat lines had a low capacity to absorb soil nitrogen, but had high nitrate reductase activity during the autumn and had a high efficiency in translocation of reduced N into the grain. Finally, they added that after heading, the high-protein lines increased more rapidly in percent N in the grain than low-protein lines, and that the greatest peak of percent N occurred during the last weeks before maturity.

In rice, Perez, et al. (17) found that nitrate reductase activity in leaf blades was low after transplanting, and reached the highest peak of the activity at 4 weeks after transplanting. They also found that the three rice varieties studied had similar grain yield, but the variety with highest percentage of protein tended to translocate more leaf N to the developing grains than the varieties with lower grain protein content.

Nitrogen determinations on high and low protein wheat varieties at various stages of growth were made by Seth, et al. (22). They found that the protein content of the vegetative parts of low protein varieties was as high as that of the high protein varieties. They stated that the higher nitrogen content of the kernels of high protein varieties may be due to either absorption of more nitrogen from the soil or to translocation of a high proportion of the absorbed nitrogen from the vegetative parts to the kernels. Also, they found that higher protein conten may be associated with a higher rate of protein synthesis in the developing kernels.

CHAPTER III

METHODS AND MATERIALS

Genetic Population

A total of 111 'NE 65679' / 'D 145B4' F_2 subpopulations were evaluated in the F_4 generation. Included in the test were the two parental lines, NE 65679 and D 145B4, as well as seven standard check varieties. These subpopulations, hereafter referred to as F_4 lines, are presumed to represent a random sample of lines from the cross since they had not been selected for any of the characters evaluated in this study. Also, there had been no conscious within line selection. Therefore each F_4 line could be regarded as the random progeny derived from a single F_2 plant. The F_4 lines were derived from F_2 plants used in a previous experiment conducted at the Oklahoma Agricultural Experiment Station (6). The subpopulations had then been grown as F_3 lines in 1971-72 in single row plots for increase so that sufficient quantities of seed would be available for a replicated test in the F_4 generation.

NE 65679 is a high-protein experimental line developed at the Nebraska Agricultural Experiment Station from a cross of 'Atlas 66' and 'Comanche'. NE 65679 is a standard height, late maturing variety which has been relatively low in grain yield potential when grown in Oklahoma. It is high in grain protein content, averaging 2 to 3 percentage points higher than varieties grown commercially in Oklahoma. D 145B4 is a 'Triumph-Type' experimental line tracing to seed stocks bequeathed to Oklahoma State University by the late Joseph E. Danne. D 145B4 is a standard height, early maturing variety and has high grain yield potential. D 145B4 tends to have relatively low grain protein content for a variety in the hard red winter class. The seven standard check varieties were: 'Caprock', 'Centurk', 'Danne', 'Nicoma', 'Purdue 4930', 'Scout 66', and 'Tam W 101'. This set of check varieties was chosen to provide a range in maturity, height, yield potential, and other characteristics.

Field Layout and Cultural Practices

The experiment was planted on a Norge loam soil at the Oklahoma Agricultural Experiment Station, Stillwater, on October 2, 1972. A randomized block design with four replications was used. Each replication contained 120 plots. Each plot was a single row, 3 m in length with 30 cm spacing between plots. Nine grams of seed were planted in each plot which was equivalent to the standard seeding rate for wheat (60 lbs/acre). The 111 F_4 lines, two parents and the standard check varieties were assigned at random in each replication. Uniform emergence of seedlings was obtained and good stands were established on all plots.

Nitrogen fertilizer in the form of ammonium nitrate was applied at the rate of 20 kg/ha of actual N before seeding. A topdressing application of nitrogen fertilizer in the form of ammonium nitrate was made on February 9, 1973 at the rate of 45 kg/ha of actual N.

During the heading period, individual plots were checked each day for date of heading. Plots were harvested between June 8 and 12, 1973.

Sampling Procedures

Heading date, grain yield, straw yield, grain protein content, and straw protein content were the five primary variables investigated in this study. Two secondary or derived variables were included in the statistical analysis. They were grain protein production in kg/ha and straw protein production in kg/ha. An additional derived variable, grain to straw ratio was calculated but was not statistically analyzed.

Heading date was used as a measure of maturity of individual lines studied. Plots were checked each day and the date of heading was recorded as the number of days after March 31, 1973 when approximately 50% of the heads in each plot had completely emerged from the boot.

Grain yield was determined from a 2.4 m distance of each plot. Individual plots were harvested by the use of a hand sickle and stems were cut at a uniform distance above the soil surface. Prior to threshing the bundle (grain and straw) weight of individual plots was recorded. After threshing, the grain yield was determined for each plot and was expressed in kg/ha.

Straw yield was obtained by subtracting grain weight from the bundle weight and was expressed in kg/ha.

Grain protein content was expressed in percentage of protein in the grain. A 10g sample of grain from each plot was taken randomly.

These samples were then ground in a laboratory cyclone mill and a 1g subsample was taken from each sample for protein analysis using the boric acid modification of the Kjeldahl procedure. Protein analyses were made in the Oklahoma State University Wheat Quality Laboratory.

Straw protein content was determined on a sample from 20 wheat plants which had been taken from the ends of each plot just prior to harvest. These samples were then threshed in a laboratory head thresher where the grain was removed and the straw, including rachis, glumes, and awns from each sample was saved. The straw samples were then ground in a laboratory hammer mill and a 1g subsample was taken for protein analysis which was determined by the same procedure as described above for grain protein.

Grain protein production was computed as the product of grain yield in kg/ha × percent grain protein divided by 100.

Straw protein production was computed as the product of straw yield in kg/ha × percent straw protein divided by 100.

Grain to straw ratio was calculated by dividing grain yield in kg/ha by straw yield in kg/ha.

Statistical Analyses

Analyses of variance of the seven variables (not including grain to straw ratio) were conducted according to two sources of data. One source consisted of 111 F_4 lines, the two parents, and the seven standard check varieties making a total of 120 entries. The other source consisted of the 111 F_4 lines only.

Correlation coefficients were computed for all two-way comparisons of the seven variables. These were computed also on the two sources of data as described above. The correlation coefficients were computed as a part of the analysis of variance from which replication differences had been removed. Thus, the correlation coefficients are nearly the same as simple correlation coefficients but should tend to be more precise since they have been corrected for replication effects.

Appropriate statistical tests to measure significant differences were made for correlation coefficients as well as for mean differences for each of the seven variables.

CHAPTER IV

RESULTS AND DISCUSSION

General Growing Conditions

Growing conditions were favorable throughout the crop season. Cool and wet conditions prevailed during the spring and enhanced the production of grain and straw in the study. The average grain yield of the 111 F_4 lines in the test was 3870.2 kg/ha (56 bu/acre) and the highest and lowest F_4 lines yielded 4654.3 kg/ha (65 bu/acre) and 2990.4 kg/ha (45 bu/acre), respectively. These yield levels provide an indication of the favorable growing conditions. All F_4 lines were relatively tall, as were both parents. Just before maturity, strong winds and heavy rainfall caused some lodging. However, the lodging was not considered to be serious enough to affect measurements of yeilds and other characters. A leaf rust infection occurred late in the spring and all entries were scored for leaf rust reaction. Since all F_4 lines exhibited similar responses to this disease, leaf rust reaction was not included in the analysis of variance or comparisons among means.

The favorable growing conditions, especially excessive rainfall, no doubt tended to make the average grain protein content lower. The grain protein content of the high-protein parent, NE 65679, was 14.43% whereas that of the other parent, D 145B4, was 10.83%.

This was 2 to 3 percentage points lower than would be expected from these genotypes under drier growing conditions. This is consistent with reports from other workers regarding the effect of soil moisture on protein content (19, 21).

Comparisons of F_4 Lines with Parental Values

Mean squares for seven variables from the analyses of variance based on 120 entries are presented in Table I. A separate analysis of the same variables was conducted on the F_4 lines alone. Mean squares from this analysis are given in Table II. In both cases, differences among genotypes for all variables were statistically significant at the .01 probability level, indicating that differences were not due solely to parents and check varieties.

Ranges and means of the F_4 lines are compared with parental means for the 7 variables. These comparisons are presented in Table III. For heading date, the mean of all F_4 lines was 28.7 days as compared to 31.6 days for the midparent value and 25.5 days for the early parent, D 145B4. Among all F_4 lines, 26.1% matured earlier than the early parent and 73.9% were between the two parents. This indicates a shift toward early maturity for the F_4 lines. Moreover, no F_4 line headed as late as the late parent.

For grain yield the mean of all F_4 lines was similar to the midparent value (3870.2 kg/ha compared to 3811.1 kg/ha). There was a considerable range in grain yield among the F_4 lines. As shown in Table III, the highest yielding F_4 line exceeded D 145B4, the high yielding parent, by 493.4 kg/ha. It will be noted in Appendix Table VII that D 145B4 was the highest in grain yield among

TABLE I

MEAN SQUARES FROM THE ANALYSIS OF VARIANCE OF 120 ENTRIES (111 NE 65679/D145B4 F_4 LINES PLUS, 2 PARENTS AND 7 STANDARD VARIETIES) STILLWATER, 1973

Source	d.f.	Variable						
		Heading Date (Days)	Grain Yield (kg/ha × 1000)	Straw Yield (kg/ha × 10000)	Grain Protein (%)	Straw Protein (%)	Grain Protein (kg/ha × 100)	Straw Protein (kg/ha × 100)
Rep.	3	37.43**	6671.87**	8752.01**	15.17**	12.97**	1369.33**	2385.76**
Entry	119	80.29**	499.17**	142.71**	2.03**	0.19**	98.80**	20.63**
Error	357	1.43	194.01	52.38	0.46	0.11	37.52	10.17

** Significant difference at .01 level

TABLE II

MEAN SQUARES FROM THE ANALYSIS OF VARIANCE FOR 111 NE65679/D145B4 F_4 LINES, STILLWATER, 1973

Source	d.f.	Variable						
		Heading Date (Days)	Grain Yield (kg/ha × 1000)	Straw Yield (kg/ha × 10000)	Grain Protein (%)	Straw Protein (%)	Grain Protein (kg/ha × 100)	Straw Protein (kg/ha × 100)
Rep.	3	37.57**	7161.43**	8502.59**	14.79**	12.12**	1446.27**	2287.53**
Entry	110	80.25**	465.53**	124.87**	1.53**	0.18**	93.15**	20.64**
Error	330	1.46	187.20	53.03	0.43	0.11	36.87	10.18

** Significant difference at .01 level

TABLE III

RANGES AND MEANS OF NE 65679/D145B4 F_4 LINES FOR 7 VARIABLES COMPARED TO PARENTAL VALUES

Genotype	Heading Date (Days)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Grain Protein (%)	Straw Protein (%)	Grain Protein (kg/ha)	Straw Protein (kg/ha)
Highest F_4 Line	37.0	4654.3	8321.9	14.33	3.10	616.9	236.0
Lowest F_4 Line	22.3	2990.4	5812.5	11.40	1.95	376.9	125.2
Mean of all F_4's	28.7	3870.2	7123.9	12.45	2.44	481.8	176.1
P_1(NE 65679)	37.8	3461.3	7480.9	14.43	2.45	500.0	185.9
P_2(D145 B4)	25.5	4160.9	6179.2	10.83	2.58	450.3	158.8
Midparent Value	31.6	3811.1	6830.1	12.63	2.51	475.2	172.4

the parents or standard check varieties. The F_4 line lowest in grain yield was 470.9 kg/ha lower than NE 65679, the low yielding parent.

The range of F_4 lines exceeded the parental values for straw yield and the mean of all F_4's exceeded the midparent value for this character by 293.3 kg/ha. Straw yield was nearly twice that of grain yield for most comparisons which indicated a preponderance of straw production over grain. A more desirable grain to straw ratio would have been 0.75 to 1.0.

The F_4 lines fell within the parental values for percent grain protein. The highest F_4 line produced 14.33% grain protein compared to the high-protein parent, NE 65679, which had 14.43%. The lowest F_4 line had 11.40% grain protein compared with 10.83% for the low-protein parent, D 145B4. The mean of all F_4 lines was very similar to the midparent value (12.45% vs. 12.63%). The fact that no transgressive segregation was observed for grain protein could be due to the possibility that plus and minus factors were isodirectionally distributed in the parents. NE 65679 may have had all the plus factors and D 145B4 all the minus factors. If this were the case, no transgressive segregation would be expected.

For straw protein content, the two parents expressed very similar levels in this character, even though they differed widely in percent grain protein. D 145B4 produced 2.58% straw protein whereas NE 65679 produced 2.45%. The mean of all F_4 lines was 2.44% while the range was 1.95% to 3.10%.

For grain protein production per ha as well as straw protein production per ha, the range among the F_4 lines exceeded the parental values. For both variables, the mean values for all F_4 lines were similar to their corresponding midparent values.

The relationship between grain yield and grain protein content would be of major importance in a breeding program concerned with the concurrent improvement in these two traits. Three grain yield groups (high, intermediate, and low) of 10 F_4 lines each were examined to determine the possible presence and extent of association of grain protein content and other characters with grain yield (Table IV).

It is of interest to note that the average grain protein content of all three yield groups was very similar. The average grain yield was 4456.2, 3932.9, and 3198.6 kg/ha for the high, intermediate and low groups, respectively. The average grain protein content for these three groups was 12.45%, 12.65%, and 12.58%, respectively. Straw protein content was slightly lower in the high yield group than in the other two groups but the differences were rather small.

For heading date, the high yield group averaged 5 days earlier than the intermediate group and 7 days earlier than the low yield group. This indicates that the high-yield group contained a preponderance of early maturing lines. However, these details will be further discussed in the next section. The grain to straw ratio was slightly higher in the high yield group than in the other two groups indicating a more favorable grain to straw ratio for the high yield group. The low yield group had the lowest grain to straw ratio which was 0.49, indicating that the low yielding lines produced twice as much straw as grain. However, the variation in this character was not great and the trends shown here may not be meaningful in

TABLE IV

MEANS FOR FIVE VARIABLES OF 30 NE65679/D145B4 F_4 LINES ARRANGED IN HIGH, INTERMEDIATE AND LOW GRAIN YIELD GROUPS

Entry No.	Seln. No.	Grain Yield (Rank)	Grain Yield (kg/ha)	Grain Protein (%)	Straw Protein (%)	Heading Date (Days)	Grain to Straw Ratio
			High Yield Group				
41	21B	1	4654.3	13.28	2.68	28.3	0.57
32	6B	2	4608.3	12.98	2.48	24.0	0.58
53	48B	3	4554.5	12.55	2.38	23.5	0.58
47	33B	4	4534.3	11.73	2.23	27.3	0.59
19	38A	5	4419.9	12.75	2.30	23.3	0.60
57	3C	6	4413.2	12.35	2.63	28.0	0.58
27	52A	7	4389.7	12.20	2.43	23.5	0.63
78	40C	8	4386.3	12.33	2.43	25.5	0.61
24	44A	9	4332.4	11.98	2.58	25.5	0.59
90	9D	10	4268.6	12.35	1.98	22.5	0.59
		$\bar{x}$	4456.2	12.45	2.05	25.1	0.59
			Intermediate Yield Group				
82	48C	51	3965.8	12.20	2.45	27.8	0.54
34	10B	52	3949.0	11.70	2.23	23.3	0.60
116	52D	53	3949.0	12.98	2.30	27.5	0.56
59	11C	54	3935.6	12.90	2.70	34.5	0.49
70	29C	55	3935.6	12.63	3.10	35.0	0.53
105	32D	56	3925.5	13.20	2.73	24.5	0.60
80	46C	57	3918.7	13.23	2.60	34.2	0.53
85	53C	58	3918.7	12.80	2.33	35.3	0.52
36	12B	59	3915.4	12.78	2.80	35.5	0.47
86	2D	60	3915.4	12.08	2.18	25.5	0.56
		$\bar{x}$	3932.9	12.65	2.54	30.3	0.54
			Low Yield Group				
25	45A	102	3346.9	11.85	2.65	28.3	0.51
29	4B	103	3316.6	12.28	2.38	35.7	0.57
40	20B	104	3309.9	13.68	2.63	35.0	0.46
103	30D	105	3286.4	11.65	2.23	34.3	0.48
95	17D	106	3212.4	11.93	2.40	35.0	0.48
12	25A	107	3185.5	13.63	2.50	28.3	0.45
4	11A	108	3124.9	12.95	2.45	28.0	0.53
83	51C	109	3114.8	12.05	2.10	26.3	0.52
8	17A	110	3098.0	12.88	2.53	33.8	0.44
3	5A	111	2990.4	12.88	2.93	35.3	0.49
		$\bar{x}$	3198.6	12.58	2.48	32.0	0.49
		LSD .05	599.6	0.91	0.46	1.7	1/
		.01	788.0	1.20	0.60	2.2	

1/ No LSD computed for grain to straw ratio.

projecting from this population to others. Also, grain to straw ratio values in some instances could have been affected by interplot competition arising from the use of single-row plots.

Correlation of Variables

The associations among the variables were examined by computing correlation coefficients based on 120 entries (111 F_4 lines plus 9 standard check varieties) as well as on the 111 F_4 lines alone. An examination of these two sets of correlation coefficients revealed no important differences between the two sources of data used. Therefore only the correlations based on the 111 F_4 lines will be discussed. These are presented in Table V.

The results indicated that grain yield was negatively correlated with heading date ($r = -0.303^{**}$) which supports the trend shown previously that the highest yielding group of F_4 lines were characterized by early maturity (Table IV). Similar results were reported by Stuber, et al. (24) who found a very high negative correlation between grain yield and flowering date with a coefficient of -0.902 in the F_1 of a cross between Wichita and Atlas 66.

Of considerable interest in terms of the objective of this study was the relationship between grain yield and grain protein content. There is a general assumption among wheat research workers that low grain protein content is associated with high grain yield (3, 4, 6, 25). However, in this present study, this general relationship was not found. The correlation coefficient between grain yield and grain protein content was very low and not significantly different from zero (-0.031^{ns}). This is further supported by the absence of an association

TABLE V

CORRELATION COEFFICIENTS AMONG 7 VARIABLES BASED ON 111 NE 65679 / D 145 B4 F_4 LINES

Variable	Heading Date (Days)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Grain Protein (%)	Straw Protein (%)	Grain Protein (kg/ha)	Straw Protein (kg/ha)
Heading Date (Days)	—	-0.303**	0.241*	0.299**	0.499**	-0.130ns	0.481**
Grain Yield (kg/ha)			0.531**	-0.031ns	-0.156ns	0.871**	0.212*
Straw Yield (kg/ha)				0.306**	0.232*	0.617**	0.752**
Grain Protein (%)					0.394**	0.462**	0.437**
Straw Protein (%)						0.053ns	0.808**
Grain Protein (kg/ha)							0.400**
Straw Protein (kg/ha)							—

*Significant difference at .05 level

**Significant difference at .01 level

between grain yield and protein content as shown previously in Table IV. These findings could have important implications in terms of breeding programs with this genetic population and perhaps with other populations derived from similar genetic sources of high protein. The results indicate that no strong genetic barriers exist which would prevent the development of high yielding varieties which also possess the genetic potential for high grain protein content.

As shown in Table V, grain protein content was positively correlated with heading date ($r = 0.299^{**}$), indicating that the late maturing lines had higher grain protein levels. The positive correlation between grain protein content and heading date agrees with the findings of several workers (24, 25).

Grain protein content was positively correlated with straw protein content ($r = 0.394^{**}$). It has been suggested that high grain protein content may be made at the expense of protein in the straw so that the relationship between grain and straw protein content would be a negative one. In the present study, this was not the case. An explanation could be that because of favorable growing conditions, protein in the vegetative parts of the plant were not translocated to the grain at the same rates that would be found under more normal growing conditions. This resulted in lower than normal grain protein levels for all genotypes and could be the reason for the positive relationship between grain and straw protein content.

Straw yield was positively associated with grain yield ($r = 0.531^{**}$) indicating that conditions which influenced grain yield also had a similar influence on straw yield.

The highest correlation observed in this study was that between grain yield and grain protein production per ha ($r = 0.871^{**}$). This was to be expected since grain protein production per ha is a derived variable influenced by grain yield per ha as well as by grain protein content. Since the correlation between grain yield and grain protein content was not significantly different from zero, any change in grain yield should be accompanied by a corresponding change in grain protein production per ha.

Distribution Patterns for Various Character Combinations

The distribution patterns of individual F_4 lines in relation to parental values should provide a more obvious understanding of the relationship between variables than that indicated by correlation coefficients. Also, information provided by these distribution patterns would be useful for a breeding program in terms of selection of promising individual lines. The distribution patters for three important character combinations will be discussed.

The distribution of 111 F_4 lines plotted by heading date and grain yield is shown in Figure 1. The F_4 lines formed two distinct maturity groups. The early maturing group centered around the early parent, D 145B4, and contained approximately two-thirds of the lines whereas the late maturing group, composed of the remaining one-third of the lines, fell between the midparent value and the late parent, NE 65679. The highest yielding lines fell in the early maturing group and most of the highest-yielding F_4 lines fell within 3 days of the heading date of the early parent, D 145B4.

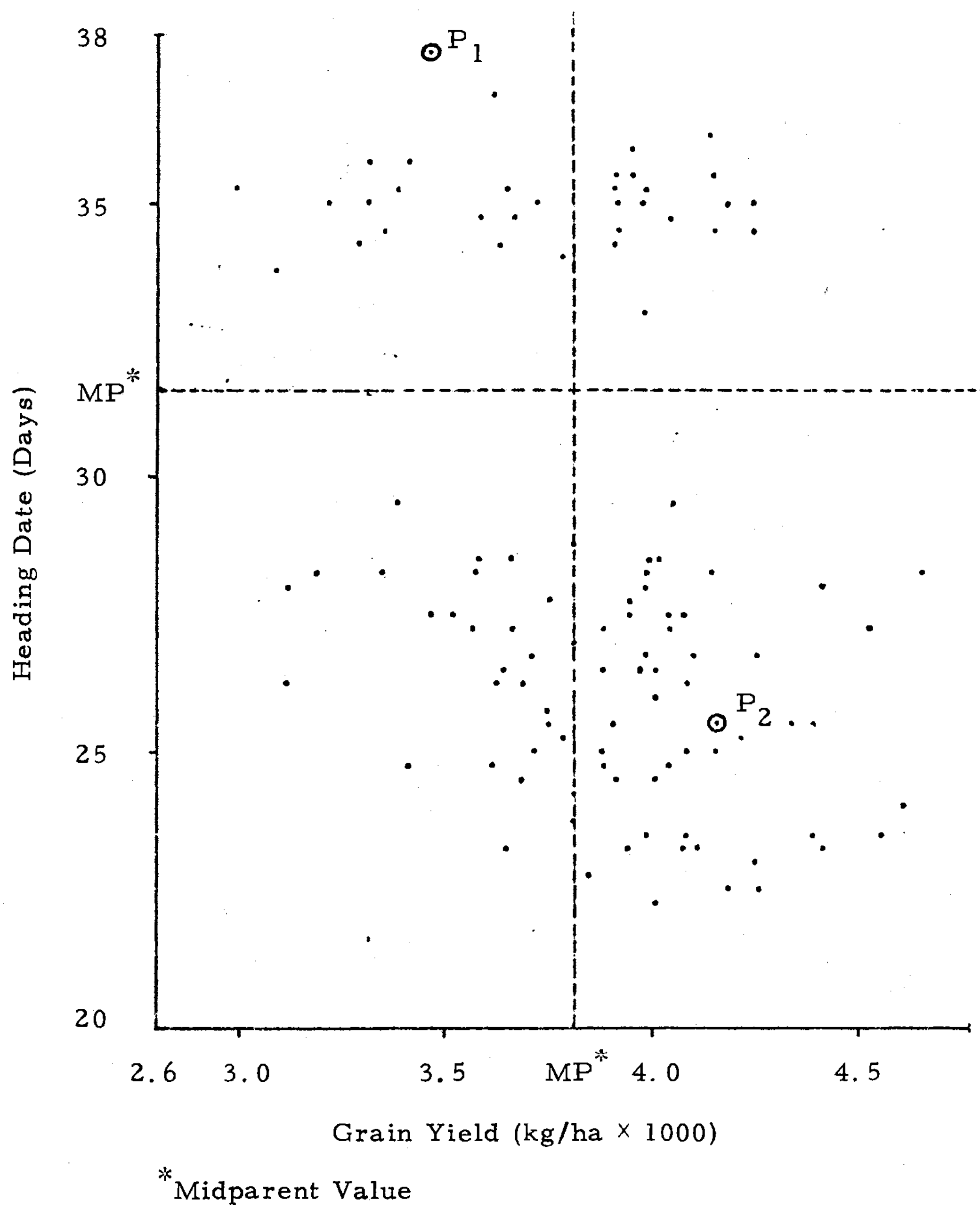
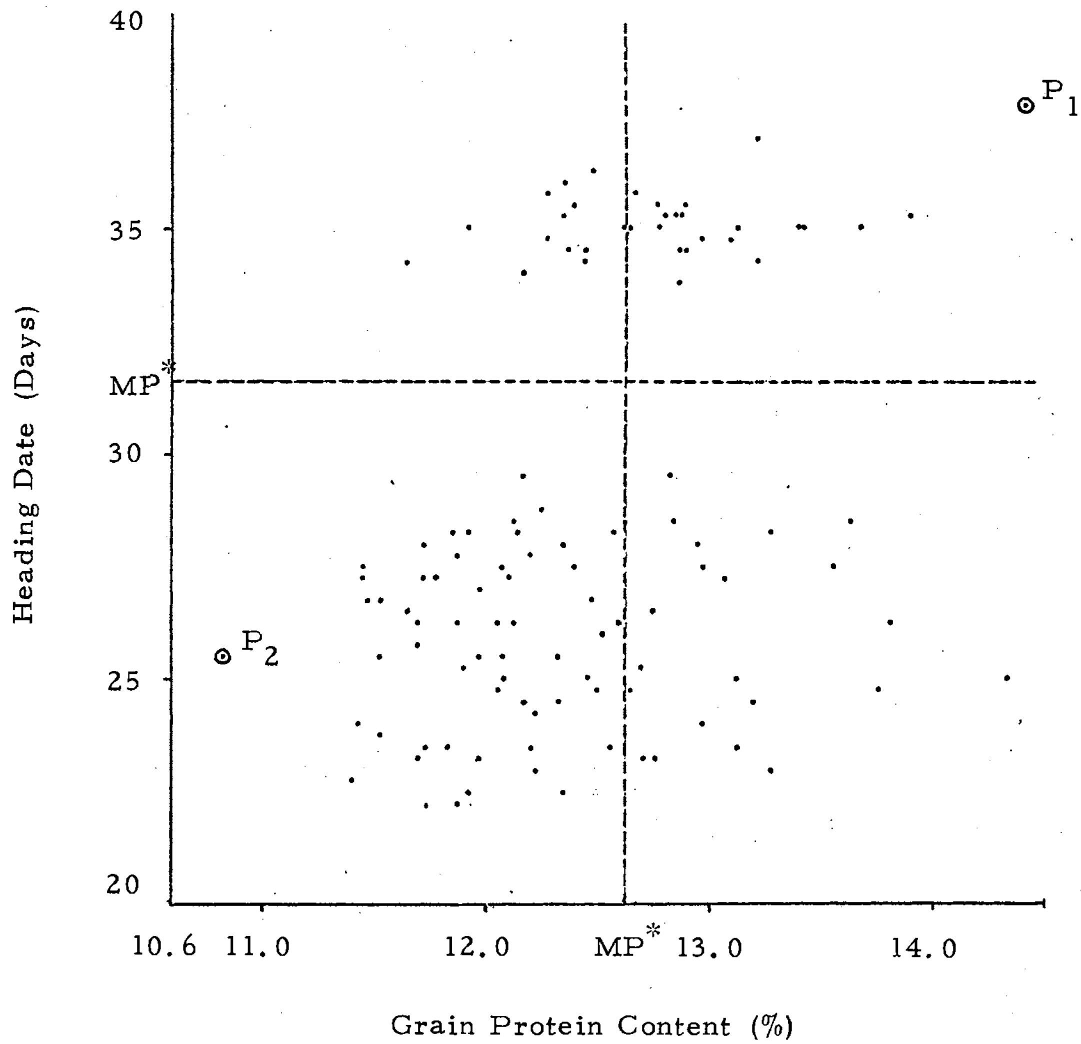


Figure 1. Distribution Pattern of 111 F_4 Lines Plotted by Heading Date and Grain Yield as Compared to the Parental Values P_1 = NE 65679, P_2 = D 145B4

The distribution of F_4 lines plotted by heading date and grain protein content is shown in Figure 2. Although a statistically significant positive correlation between these two traits ($r = 0.299^{**}$) was noted previously, the distribution pattern indicated that grain protein levels were distributed much the same in the early maturing group as in the late maturing group. However, there was a concentration of lines in the early maturity, low protein sector of Figure 2. The late maturing group was about equally distributed on either side of the midparent value with regard to grain protein content. Of interest in a breeding program for Oklahoma would be the genotypes contained in the lower-right-hand secton of Figure 2. Those are the lines with early maturity and high grain protein content.

The distribution pattern for grain yield and grain protein content is shown in Figure 3. As mentioned previously, the correlation coefficient between these two characters ($r = -0.031^{ns}$) was not significantly different from zero. This lack of relationship between grain yield and grain protein content can be seen in Figure 3. The absence of any relationship between the two traits was unexpected in view of reports by previous workers (3, 4, 6, 25). The possibility exists that this lack of association resulted from the unusually high rainfall received in the 1973 crop year which apparently depressed grain protein levels to such an extent that even the lines with the highest protein content were much lower than expected. It is of interest to note that 25 F_4 lines exceeded the midparent values for both grain yield and grain protein content (upper-right-hand sector of Figure 3). These are the lines that would be of interest in a selection



*Midparent Value

Figure 2. Distribution Pattern of 111 F_4 Lines Plotted by Heading Date and Grain Protein Content as Compared to the Parental Values P_1 = NE65679, P_2 = D145B4

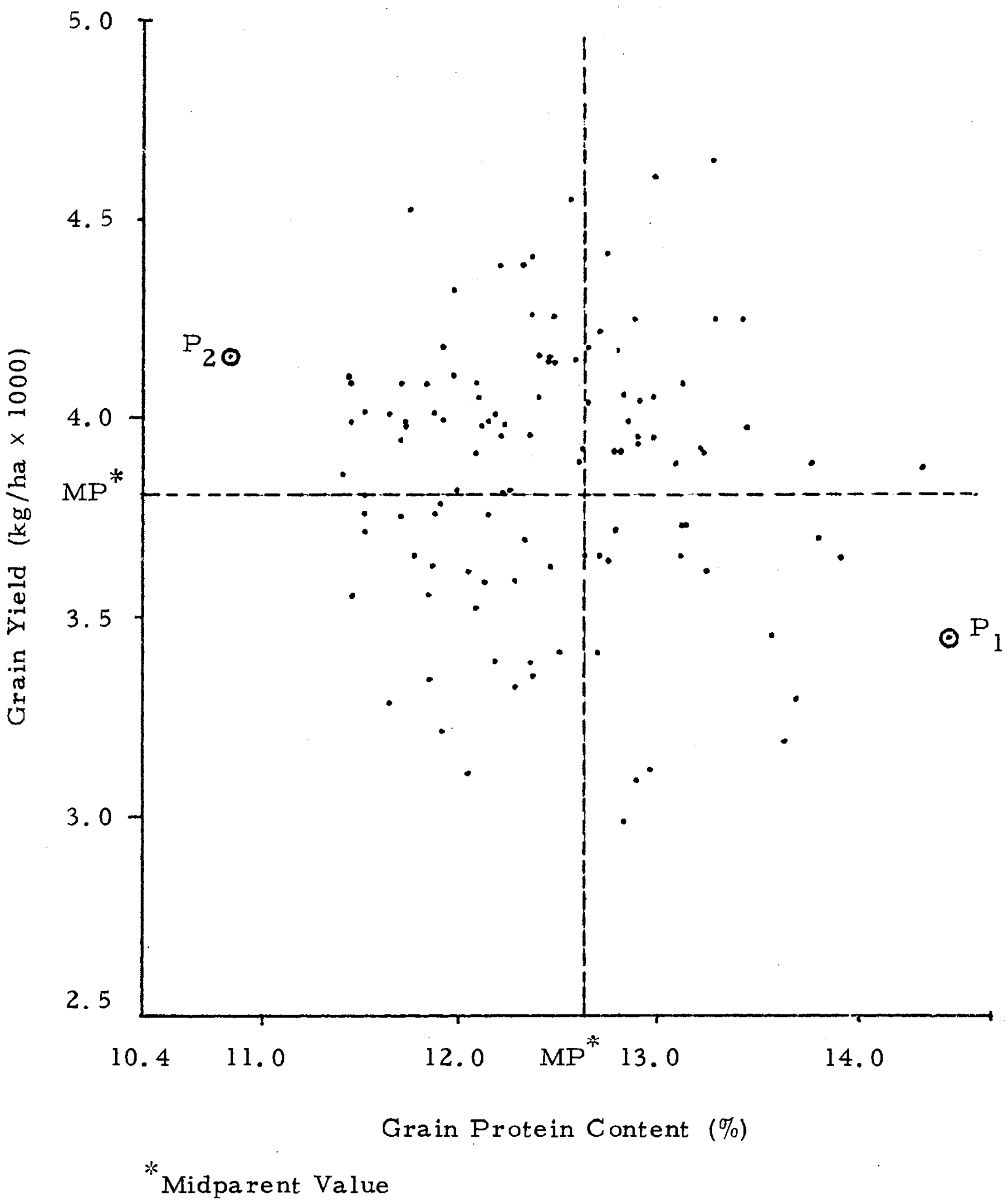


Figure 3. Distribution Pattern of 111 F_4 Lines Plotted by Grain Yield and Grain Protein Content as Compared to the Parental Values P_1 = NE65679, P_2 = D 145B4

program concerned with the concurrent improvement of grain yield and grain protein content.

The 25 lines which exceeded the midparent values for both grain yield and protein content fell into two maturity groups as shown in Table VI. Fourteen lines comprised the early maturing group, and eleven lines comprised the late maturing group. Means for heading date, grain protein content, and grain yield of the early group were 25.6 days, 13.1%, and 4135.7 kg/ha, respectively. In the late maturing group, means of heading date, grain protein content, and grain yield were 34.9 days, 13.0% and 4031.0 kg/ha, respectively. The average grain protein content was nearly the same in both maturity groups while the average grain yield was slightly higher in the early maturing group.

In a breeding program concerned with the development of high yielding, high grain protein wheat varieties for Oklahoma, early maturity would be an important consideration. During 1973, approximately 60% of the wheat acreage in the state was seeded to early maturity varieties and it is expected that early maturing varieties will continue to be favored by wheat growers in Oklahoma. Therefore, of the total 111 F_4 lines examined in this study, 14 lines (12.6%) appeared to have desirable performance levels with regard to maturity, grain protein content and grain yield to warrant further selection studies leading toward variety development.

TABLE VI

MEANS FOR THREE VARIABLES OF 25 NE 65679/D 145B4 F_4 LINES THAT EXCEEDED MIDPARENT VALUES FOR GRAIN YIELD AND PROTEIN ARRANGED IN EARLY AND LATE MATURING GROUPS

Entry No.	Heading Date (Days)	Grain Yield		Grain Protein (%)
		Rank	kg/ha	
Early Maturity Group that Exceeded Midparent Values for Grain Yield and Protein				
7	29.5	7	4060.0	12.8
19	23.3	3	4419.9	12.8
32	24.0	2	4608.3	13.0
41	28.3	1	4645.3	13.3
42	27.3	12	3898.6	13.1
44	28.5	8	4036.5	12.9
49	24.8	13	3898.6	13.8
54	23.3	6	4086.9	13.1
64	23.0	4	4245.0	13.3
105	24.5	11	3925.5	13.2
109	25.3	5	4221.5	12.7
112	25.0	14	3875.0	14.3
116	27.5	10	3949.0	13.0
117	24.8	9	4029.8	12.7
$\bar{x}$	25.6	—	4135.7	13.1
Late Maturity Group that Exceeded Midparent Values for Grain Yield and Protein				
20	35.0	6	3979.3	13.4
22	35.3	5	3992.8	12.9
36	35.5	11	3915.4	12.8
37	35.0	3	4181.1	12.7
51	34.5	1	4255.1	12.9
56	35.0	2	4255.1	13.4
59	34.5	7	3935.6	12.9
70	35.0	8	3935.6	12.6
80	34.3	9	3918.7	13.2
85	35.3	10	3918.7	12.8
102	34.8	4	4053.3	13.0
$\bar{x}$	34.9	—	4031.0	13.0
P_1(NE 65679)	37.8		3461.3	14.4
P_2(D 145B 4)	25.5		4160.9	10.8
Midparent	31.6		3811.1	12.6

CHAPTER V

SUMMARY AND CONCLUSIONS

A total of 111 randomly chosen F_2 subpopulations were evaluated as lines in the F_4 generation. These lines had been derived from a cross between NE 65679, an Atlas 66 high-protein derivative, and D 145B4, a low-protein, high yielding, early maturing line. The 111 F_4's, along with both parents and seven standard varieties, Caprock, Centurk, Danne, Nicoma, Purdue 4930, Scout 66, and Tam W 101 were examined in a randomized block design with four replications. Plots were single rows 3 m in length and were seeded at the rate of 70 kg/ha. The field experiment was conducted in 1972-73 at the Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma.

The objectives of this study were to determine the relationship of protein content to grain yield and to identify lines in this population having both high yield and high protein content for use in further breeding and selection studies.

The results indicated highly significant differences among genotypes for heading date, grain yield, straw yield, grain protein content, straw protein content, grain protein production per ha and straw protein production per ha. A total of 18 F_4 lines exceeded the high parent in grain yield, whereas all F_4 lines fell within the parental values for grain protein content.

The association among 7 variables was studied by correlation coefficients as well as by distribution patterns. Grain yield was negatively correlated with heading date ($r = -0.303^{**}$) whereas grain protein content was positively correlated with heading date ($r = 0.299^{**}$). The generally accepted rule of an inverse relationship between grain yield and grain protein content was not observed in this study. The correlation coefficient between grain yield and grain protein content was very low ($r = -0.031^{ns}$) and not significantly different from zero. This suggests that this genetic population and perhaps other populations derived from the same genetic source for high protein could be used successfully in a breeding program concerned with the concurrent improvement of grain yield and grain protein content. In relation to the breeding of wheat varieties for Oklahoma, grain yield, grain protein content, and heading date are important characters. In this regard, 14 out of 111 F_4 lines (12.6%) exceeded midparent values for grain yield and grain protein content, and also had early maturity. The results indicate that varieties with high yield and high protein and early maturity could be developed by further breeding and selection programs from the population examined in the present study.

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APPENDIX

TABLE VII

MEANS FOR FIVE VARIABLES OF 111 F_4 LINES, P_1, P_2, AND 7 STANDARD VARIETIES ARRANGED FROM HIGHEST TO LOWEST FOR GRAIN YIELD

Entry No.	Seln. No.	Grain Yield (Rank)	Grain Yield (kg/ha)	Grain Protein (%)	Straw Protein (%)	Heading Date (Days)	Grain to Straw Ratio
41	21B	1	4654.3	13.28	2.68	28.3	0.57
32	6B	2	4608.3	12.98	2.48	24.0	0.58
53	48B	3	4554.5	12.55	2.38	23.5	0.58
47	33B	4	4534.3	11.73	2.23	27.3	0.59
19	38A	5	4419.9	12.75	2.30	23.3	0.60
57	3C	6	4413.2	12.35	2.63	28.0	0.58
27	52A	7	4389.7	12.20	2.43	23.5	0.63
78	40C	8	4386.3	12.33	2.43	25.5	0.61
24	44A	9	4332.5	11.98	2.58	25.5	0.59
90	9D	10	4268.6	12.35	1.98	22.5	0.59
43	24B	11	4261.8	12.48	2.45	26.8	0.57
51	41B	12	4255.1	12.88	2.53	34.5	0.57
56	2C	13	4255.1	13.40	2.70	35.0	0.54
64	20C	14	4245.0	13.28	2.40	23.0	0.56
109	38D	15	4221.5	12.70	2.18	25.3	0.59
37	13B	16	4181.1	12.65	2.40	35.0	0.51
108	37D	17	4181.1	11.93	2.28	22.5	0.61
60	14C	18	4167.7	12.45	2.45	34.5	0.53
87	3D	19	4160.9	12.40	2.40	35.5	0.56
45	32B	20	4157.6	12.45	2.33	25.0	0.59
101	27D	21	4150.9	12.58	2.35	28.3	0.55
99	25D	22	4140.8	12.48	2.55	36.3	0.55
89	5D	23	4110.5	11.98	2.35	23.3	0.61
100	26D	24	4100.4	11.43	2.40	26.5	0.56
38	18B	25	4093.7	12.08	2.13	25.0	0.55
75	38C	26	4093.7	11.83	2.15	23.5	0.61
79	45C	27	4090.3	11.70	2.28	26.3	0.51
54	51B	28	4086.9	13.13	2.40	23.3	0.60
9	18A	29	4080.2	11.45	2.28	27.5	0.62
7	14A	30	4060.0	12.83	2.78	29.5	0.57
74	37C	31	4053.3	12.10	2.30	27.3	0.54
102	28D	32	4053.3	12.98	2.45	34.8	0.54
33	7B	33	4043.2	12.40	2.48	27.5	0.52
44	25B	34	4036.5	12.85	2.45	28.5	0.59
117	53D	35	4029.8	12.65	2.73	24.8	0.54
84	52C	36	4016.3	11.88	2.25	22.3	0.61
13	26A	37	4012.9	12.53	2.35	26.0	0.58
98	20D	38	4012.9	12.18	2.18	24.5	0.50
96	18D	39	4009.6	11.65	2.08	26.5	0.55
114	48D	40	3996.1	11.93	2.15	28.3	0.58
10	20A	41	3992.8	11.48	2.15	26.8	0.65

(TABLE VII Continued)

22	41A	42	3992.8	12.85	2.30	35.3	0.52
26	46A	43	3992.8	12.51	2.53	28.3	0.53
73	32C	44	3989.4	11.73	1.95	23.5	0.63
35	11B	45	3982.7	12.23	2.55	33.0	0.52
20	39A	46	3979.3	13.43	2.63	35.0	0.53
93	11D	47	3979.3	11.73	2.20	28.0	0.54
58	4C	48	3972.6	12.13	2.38	26.3	0.57
48	34B	49	3965.8	12.35	2.63	36.0	0.53
52	46B	50	3965.8	12.90	2.60	35.5	0.52
82	48C	51	3965.8	12.20	2.45	27.8	0.54
34	10B	52	3949.0	11.70	2.23	23.3	0.60
116	52D	53	3949.0	12.98	2.30	27.5	0.56
59	11C	54	3935.6	12.90	2.70	34.5	0.49
70	29C	55	3935.6	12.63	3.10	35.0	0.53
105	32D	56	3925.5	13.20	2.73	24.5	0.60
80	46C	57	3918.7	13.23	2.60	34.3	0.53
85	53C	58	3918.7	12.80	2.33	35.3	0.52
36	12B	59	3915.4	12.78	2.80	35.5	0.47
86	2D	60	3915.4	12.08	2.18	25.5	0.56
42	23B	61	3898.6	13.08	2.55	27.3	0.50
49	38B	62	3898.6	13.75	2.40	24.8	0.52
97	19D	63	3898.6	12.60	2.28	26.3	0.59
112	46D	64	3875.0	14.33	2.50	25.0	0.48
28	54A	65	3858.2	11.40	2.23	22.8	0.63
15	30A	66	3824.6	12.25	2.40	28.8	0.54
69	28C	67	3821.2	11.98	2.60	27.0	0.57
94	12D	68	3817.8	12.25	2.38	24.3	0.55
30	5B	69	3807.8	11.53	2.13	23.8	0.54
55	53B	70	3797.7	11.90	2.30	25.3	0.56
88	4D	71	3774.1	12.18	2.68	34.0	0.54
110	39D	72	3760.7	11.53	2.50	25.5	0.52
118	54D	73	3760.7	11.88	2.25	27.8	0.57
50	39B	74	3753.9	11.70	2.58	25.8	0.54
72	31C	75	3733.7	13.13	2.40	25.0	0.59
81	47C	76	3783.7	13.13	2.30	35.0	0.52
104	31D	77	3727.0	12.78	2.73	35.0	0.46
115	49D	78	3713.6	11.53	2.55	26.8	0.51
23	43A	79	3696.7	12.33	2.23	24.5	0.62
113	47D	80	3693.4	13.80	2.50	26.3	0.49
17	31A	81	3659.7	13.10	2.58	34.8	0.47
21	40A	82	3659.7	12.63	2.73	28.5	0.59
77	39C	83	3659.7	11.78	2.53	27.3	0.46
67	26C	84	3653.0	13.90	2.63	35.3	0.48
119	55D	85	3653.0	12.70	2.28	23.3	0.55
39	19B	86	3642.9	12.75	2.28	26.5	0.54
65	21C	87	3636.2	12.45	2.53	34.3	0.51
14	29A	88	3632.8	11.88	2.15	26.3	0.55
18	32A	89	3626.1	13.23	2.85	37.0	0.50
92	10D	90	3622.7	12.05	2.48	24.8	0.56

(TABLE VII Continued)

111	40D	91	3592.5	12.28	2.38	34.8	0.55
68	27C	92	3589.1	12.13	2.38	28.5	0.51
62	18C	93	3565.6	11.85	2.90	28.3	0.50
71	30C	94	3558.8	11.45	2.65	27.3	0.55
107	33D	95	3528.6	12.08	2.20	27.5	0.50
5	12A	96	3468.0	13.55	2.70	27.5	0.55
6	13A	97	3414.2	12.68	2.60	35.8	0.49
66	25C	98	3414.2	12.50	2.08	24.8	0.54
11	24A	99	3390.6	12.18	2.55	29.5	0.51
2	4A	100	3383.9	12.35	2.83	35.3	0.50
63	19C	101	3353.6	12.38	2.38	34.5	0.50
25	45A	102	3346.9	11.85	2.65	28.3	0.51
29	4B	103	3316.6	12.28	2.38	35.8	0.57
40	20B	104	3309.9	13.68	2.63	35.0	0.46
103	30D	105	3286.4	11.65	2.23	34.3	0.47
95	17D	106	3212.4	11.93	2.40	35.0	0.48
12	25A	107	3185.5	13.63	2.50	28.3	0.44
4	11A	108	3124.9	12.95	2.45	28.0	0.53
83	51C	109	3114.8	12.05	2.10	26.3	0.52
8	17A	110	3098.0	12.88	2.53	33.8	0.44
3	5A	111	2990.4	12.88	2.93	35.3	0.49
46	P_1	NE 65679	3461.3	14.43	2.45	37.8	0.46
61	P_2	D145 B4	4160.9	10.83	2.58	25.5	0.67
1	Danne		4023.0	10.98	2.68	28.0	0.65
106	Scout 66		3854.8	12.40	2.83	34.5	0.59
31	Centurk		3713.6	11.75	2.53	31.5	0.61
76	Nicoma		3653.0	11.20	2.45	26.0	0.61
120	Purdue	4930	3444.5	15.13	2.85	35.3	0.48
91	Tam W101		3431.0	11.98	2.98	30.0	0.57
16	Caprock		2697.7	12.48	2.70	28.8	0.52
	LSD .05		610.5	0.94	0.46	1.7	1/
	.01		802.2	1.23	0.61	2.2	

1/ No LSD computed for Grain: Straw Ratio

VITA

Nopporn Supapoj

Candidate for the Degree of

Master of Science

Thesis: YIELD AND PROTEIN RELATIONSHIPS AMONG F_4 LINES INVOLVING AN ATLAS 66 DERIVED HIGH PROTEIN PARENT

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