INHERITANCE OF YIELD AND PROTEIN CONTENT IN CROSSES OF MARQUIS AND KOTA SPRING WHEATS GROWN IN MONTANA[1]

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IMPROVEMENT IN YIELD AND PROTEIN CONTENT OF SPRING WHEAT DESIRED

More profitable production of hard red spring wheat is dependent upon increased acre yields, together with higher protein content of the grain. At present Marquis is the leading commercial variety of spring wheat. Under favorable conditions it is a very high yielding wheat, but under unfavorable conditions caused by drought or stem rust, such as frequently occur in the Dakotas, Kota usually outyields Marquis. This fact, together with the higher crude-protein content of the grain of Kota, made it by 1924 the second most widely grown variety of hard red spring wheat. Marquis is awnleted and Kota is awned. The awned segregates from crosses of these varieties have been higher yielding than the awnleted in Minnesota and North Dakota. The effect of awns and inheritance of yield and protein content in Marquis and Kota crosses under favorable Montana conditions is herein shown, as the results differ from those obtained in Minnesota and North Dakota under less favorable conditions.

MATERIAL AND METHODS

Much success has been obtained with crosses of Marquis and Kota wheats in North Dakota by Waldron (*10*)[2] and in Minnesota by Hayes and Aamodt (*9*). From this cross has been developed the Ceres variety, which in 1928 was grown on at least 40,000 acres. Even more promising selections from this cross are now being tested at the North Dakota and Minnesota agricultural experiment stations. All of the most promising selections developed in these States are awned. None of these has shown to as great an advantage in Montana as in the other spring-wheat States. Because of this, and to meet the popular demand in Montana for an awnless spring wheat, the writers projected the present study. It was designed to determine the relation of the length of awns to yield and protein content of the kernel under favorable conditions in Montana, and to develop awnleted strains which will be better adapted for Montana than the parent varieties and the awned strains developed from them in other States.

PARENT MATERIAL

The awnleted Marquis and awned Kota varieties have been included in the spring wheat varietal plots at the Bozeman, Moccasin, and Havre stations in Montana for several years. Milling and bak-

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[2] Reference is made by number (italic) to Literature cited, p. 217.

ing experiments, including crude-protein tests, have been made on wheat samples from these experiments.

YIELD PER ACRE

The annual and average yields from Marquis and Kota wheats obtained from the plot experiments at the experiment stations in Montana from 1921 to 1925 are given in Table 1.

TABLE 1.—*Yields of Marquis and Kota wheats grown in plot experiments at Bozeman, Moccasin, and Havre, Mont., during the five years 1921–1925*

Station and variety	Yield per acre (bushels)—						Percentage of Marquis
	1921	1922	1923	1924	1925	Average	
Bozeman:							
Marquis	42.7	64.3	57.2	36.5	47.4	49.6	100.0
Kota	40.7	57.0	40.1	36.4	43.9	43.6	87.9
Moccasin:							
Marquis	28.3	27.3	24.6	32.0	22.4	26.9	100.0
Kota	28.3	26.5	23.8	24.7	23.1	25.3	94.1
Havre:							
Marquis	11.7	5.8	20.3	12.3	16.4	13.3	100.0
Kota	15.2	3.5	21.7	12.7	18.1	14.2	106.8
Average (3 stations):							
Marquis	27.6	32.5	34.0	26.9	28.7	29.9	100.0
Kota	28.1	29.0	28.5	24.6	28.4	27.7	92.6

The data show that, under the more favorable conditions at Bozeman, Marquis exceeds Kota in average acre yield by 6 bushels, or 12.1 per cent. Under less favorable conditions at Moccasin, Marquis exceeds Kota in average yield by only 1.6 bushels, or 5.9 per cent. At Havre, under conditions unfavorable or marginal for profitable wheat production, Kota is the higher yielding variety, exceeding Marquis by 0.9 bushel, or 6.8 per cent. The average difference for the 15 station years at the 3 stations is 2.2 bushels, or 7.4 per cent, in favor of Marquis.

These yields, which were available at the time this breeding study was begun, show that under increasingly favorable conditions the awnleted Marquis has a corresponding advantage over the awned Kota.

It appeared desirable, therefore, to determine, under the most favorable conditions, whether the awns of Kota, which had been found to be an advantage in North Dakota and Minnesota (*2*, *8*), have any effect on yields in Montana.

CRUDE-PROTIEN CONTENT

The results of crude-protein tests made on samples of Kota and Marquis from the plot experiments in connection with milling and baking experiments are given in Table 2.

TABLE 2.—*Crude-protein content of Marquis and Kota wheats grown in plot experiments at Bozeman, Moccasin, and Havre, Mont., during the five years 1921–1925*

Station and variety	Crude-protein content (per cent)—						Percentage of Marquis
	1921	1922	1923	1924	1925	Average	
Bozeman:							
Marquis	13.1	10.5	13.4	10.7	11.8	11.9	100.0
Kota	16.1	12.9	16.2	12.1	13.9	14.2	119.3
Moccasin:							
Marquis	14.5	15.0	13.0	14.5	17.0	14.8	100.0
Kota	14.8	15.7	14.3	15.9	17.7	15.7	106.1
Havre:							
Marquis	17.6	15.5	13.8	12.9	15.0	15.0	100.0
Kota	18.2	14.7	14.6	13.9	16.2	15.5	103.3
Average (3 stations):							
Marquis	15.1	13.7	13.4	12.7	14.6	13.9	100.0
Kota	16.4	14.4	15.0	14.0	15.9	15.1	108.6

The data show Kota to exceed Marquis at all stations and in all years, except at Havre in 1922. The largest average difference is at Bozeman, where Kota had 2.3 per cent more protein than Marquis, an increase of 19.3 per cent. Under less favorable conditions at Moccasin and Havre the average differences decreased. The average for the 15 station years at the 3 stations shows a difference of 1.2 per cent protein, an increase for Kota of 8.6 per cent over Marquis. This is a somewhat larger difference than was found by Clark and Shollenberger (*6*) from 100 comparable samples, obtained over a period of 6 years from experiment stations in 11 States. The average difference there shown was 0.77 ± 0.21 per cent in favor of Kota.

It seemed desirable to determine in connection with yield whether there was any effect of awns on the crude-protein content of hybrid plants and strains under favorable conditions in Montana.

HYBRID MATERIAL

The crosses, Marquis × Kota and its reciprocal, were made by V. H. Florell in experiments cooperative with the California Agricultural Experiment Station, at Davis, Calif., in 1924. Some F_1 plants were grown in a greenhouse at the Arlington Experiment Farm, Rosslyn, Va., in the winter of 1924–25. In 1925 F_1 and F_2 plants were grown at the Montana Agricultural Experiment Station, Bozeman, Mont. In 1926 F_2 and F_3 progenies and in 1927 F_3 and F_4 progenies were grown at Bozeman, Mont. The more advanced material obtained from growing the F_1 plants in the greenhouse was not studied for inheritance of characters, but awnleted selections were made for practical plant-breeding purposes.

SEGREGATION OF CHARACTERS

The inheritance of dwarfness, awnedness, yield, and protein content was studied on F_2 plants grown in 1926 and F_3 strains from them grown in 1927.

In both 1926 and 1927 the hybrid and parent check plants were grown from seeds spaced 3 inches apart in rod rows 1 foot apart. In 1927 the parent checks occupied every tenth row, after single rows of nine F_3 strains arranged in the random order of harvesting in the F_2 generation.

DWARFNESS

The F_1 plants of the crosses Marquis×Kota and its reciprocal were normal in stature, but in F_2 dwarf plants were obtained. Table 3 presents the data for normals and dwarfs in the F_2 generation grown at Bozeman, Mont., in 1926. In a total of 495 F_2 plants grown, 88 were dwarf. All F_1 families of both reciprocal crosses segregated in very close agreement with a calculated 13:3 ratio.

TABLE 3.—*Segregation of 495 F_2 plants of Marquis×Kota and reciprocal crosses into two classes, normal and dwarf, when grown at Bozeman, Mont., in 1926*

Cross	Number of F_1 families	Number of F_2 plants			Deviation from 13 : 3 ratio	Probable error	Deviation ÷ probable error
		Normal	Dwarf	Total			
Marquis×Kota	4	199	41	240	4.0	4.1	1.0
Kota×Marquis	4	208	47	255	.8	4.2	.2
Total	8	407	88	495	4.8	5.9	.8

Additional data were obtained on dwarf and normal plants in the F_3 generation. Of normal plants of the Kota×Marquis cross 195 were continued in the F_3 generation. These were all of the plants of this cross from which there was sufficient seed. Only normal plants were used, because none of the dwarf F_2 plants matured seed. The results are given in Table 4.

TABLE 4.—*Breeding behavior of 195 F_3 strains grown from normal F_2 plants of Kota×Marquis crosses at Bozeman, Mont., in 1927*

Ratio	Number of F_3 strains		
	Normals breeding true	Segregating dwarfs	Total
Obtained	106	89	195
Calculated on 7 : 6 ratio	105	90	195

The data presented in Table 4 show that of the 195 F_3 families 106 bred true for normal plants, and 89 segregated for dwarf, which was very close to a calculated 7:6 ratio, the deviation being 1 ± 4.7. The F_2 and F_3 data, therefore, fit very well the theoretical 13:3 ratio.

A satisfactory interpretation of the above data can be made on a genetic basis by assuming a factor pair DD for dwarf plants and a factor pair NN for normal plants, which inhibits the action of D. As Clark (*2*) obtained no dwarfs in Kota×Hard Federation crosses, and Clark and Hooker (*5*) found segregation for dwarf plants in Marquis×Hard Federation crosses, the formula for Kota could be DDNN and that for Marquis ddnn, or vice versa. The following formulas may represent the F_2 phenotypes and genotypes and their breeding behavior in the F_3 generation:

	F_2 generation	F_3 generation
Normal:		
	1 DDNN	Breeding true.
	2 DdNN	Breeding true.
	1 ddNN	Breeding true.
	2 ddNn	Breeding true.
	1 ddnn	Breeding true.
	7	
	4 DdNn	Segregating in a 13 : 3 ratio.
	2 DDNn	Segregating in a 3 : 1 ratio.
	6	
Dwarf:		
	2 Ddnn	Segregating in a 3 : 1 ratio.
	1 DDnn	Breeding true.

The normal plants continued in the F_3 thus will have seven parts breeding true for normals and six parts segregating for dwarfs. In this study no attempt was made to separate the segregating families according to whether they were breeding in a 13:3 or a 3:1 ratio.

It is concluded that in this case Marquis and Kota differed by two genetic factors for the dwarf character. This agrees with the conclusions of Goulden (7). As he found back crosses of true breeding dwarfs to the parents produced in the F_1 generation only dwarfs in the cross of dwarf × Marquis, and only normals in the cross of dwarf × Kota, the formula for Kota would be DDNN and that Marquis ddnn.

AWNEDNESS

The spikes of F_1 plants of the Marquis × Kota and reciprocal crosses were strongly awnleted in contrast to Marquis, which is weakly awnleted, and Kota, which is awned. This showed imperfect dominance of awnletedness. In the F_2 material grown at Bozeman, Mont., in 1926, an attempt was made to separate the plants into three awnedness groups, although there was but a small difference between the strongly awnleted and the weakly awnleted classes. The F_2 data are given in Table 5.

TABLE 5.—*Segregation of 407 F_2 plants of the Marquis × Kota and reciprocal crosses into three classes for awnedness, when grown at Bozeman, Mont., in 1926*

Awnedness	Kota × Marquis	Marquis × Kota	Total	Calculated on 1:2:1 ratio [a]	Deviation from a 3:1 ratio	Probable error
Awnleted:						
Weakly	52	31	83	102		
Strongly	111	120	231	203		
Total	163	151	314	305	9	5.9
Awned	45	48	93	102	9	5.9

[a] $P=0.017$.

The data for the total F_2 are not close to a calculated 1:2:1 ratio, $P=0.017$, but are a good fit to a 3:1 ratio when the two awnleted groups are combined and compared with the awned. It will be seen that in the Kota × Marquis crosses a better fit to a 1:2:1 ratio was obtained than in the Marquis × Kota crosses. It appears that in classifying the F_2 plants too many of the weakly awnleted plants were placed with the strongly awnleted.

Most of the Kota×Marquis material was continued in the F_3, and the data are given in Table 6.

TABLE 6.—*Breeding behavior of 195 F_3 strains from Kota×Marquis wheat crosses of the three awnedness groups grown at Bozeman, Mont., in 1927*

F_2 classes and groups	Number of F_3 strains—			Total
	Awnleted	Segregating	Awned	
Awnleted:				
Weakly—				
Number	44	4		48
Percentage	91.7	8.3		
Strongly—				
Number	13	94		107
Percentage	12.1	87.9		
Awned:				
Number			40	40
Percentage			100	
Total number	57	98	40	195

It is shown in Table 6 that all of the awned F_2 plants bred true in the F_3 generation and that none of those classed as awnleted were awned. The weakly awnleted plants bred true to the extent of 91.7 per cent, whereas 87.9 per cent of the strongly awnleted plants segregated. This shows that there was considerable overlapping in the awnleted groups and that in the classification of the F_2 some heterozygous plants were classed as weakly awnleted.

Correcting the total F_2 data given in Table 5 on the basis of the breeding behavior of the F_3 strains, as shown in Table 6, the numbers would be 104 : 210 : 93, and the calculated numbers on the theoretical ratio of 1 : 2 : 1 would be 101.75 : 203.50 : 101.75. This shows a very close agreement, $P = 0.604$. This brings out the fact that the awned and awnleted classes can be accurately classified, but that in this cross it was difficult to distinguish accurately between the weakly awnleted homozygous and the strongly awnleted heterozygous groups without growing and studying an F_3 population.

From the data presented it is clearly shown that only a single genetic factor difference for awnedness is involved in Kota×Marquis crosses. This is in agreement with the early studies of Biffen (*1*) and others and with F_2 results shown by Hayes and Aamodt (*9*) for the same cross.

YIELD

Yield is largely the result of the interaction of environment and the physiological and morphological characters of the plant. Morphological characters of the wheat plant in their relation to yield have not been extensively studied. From contrasting awnedness classes in wheat crosses, Hayes (*8*) in Minnesota and Clark (*2*) in both Minnesota and North Dakota found yield to increase with the length of awns in hybrid segregates. Under the conditions at Davis, Calif., Clark, Florell, and Hooker (*4*) found that there was but a slight tendency for yield to be increased with increasing length of awns in hybrid plants and strains.

In the present work, plant yields of the parents and of hybrids in the F_2 and F_3 generations were determined for the purpose of studying the inheritance of yield and the relation of the degree of awnedness to yield under the favorable conditions at Bozeman, Mont.

The F_2 data are given in Table 7. It will be seen that Marquis had an average plant yield of 7.21 ± 0.12 and Kota had a yield of 6.73 ± 0.14. gm. The difference is 0.48 ± 0.18 and is not significant in the light of its probable error. The mean yield of the hybrids is intermediate between those of the two parents, although there are hybrid plants which exceed the upper yield limit of either parent. The coefficient of variability shows that the F_2 plant yields were significantly more variable than the plant yields of either parent. This is in accord with theoretical expectation for quantitative characters. The data on the F_3, in comparison with those from the parents, are given in Table 8.

TABLE 7.—*Plant yields of Marquis and Kota parents, total F_2 hybrids, and awnleted and awned hybrids, by 2-gm. frequency classes, at Bozeman, Mont., in 1926*

Yield per plant in grams	Number of plants of—				
	Parents and hybrids			F_2 hybrids by awnedness classes	
	Marquis	Total F_2 hybrids	Kota	Awnleted	Awned
1	2	37	6	20	17
3	18	58	28	41	17
5	42	75	53	57	18
7	57	72	46	64	8
9	53	61	36	49	12
11	18	40	18	35	5
13	5	28	7	21	7
15		10	2	8	2
17		3		3	0
19		2		1	1
Total plants	195	386	196	299	87
Mean yield	7.21±0.12	6.95±0.13	6.73±0.14	7.24±0.14	5.94±0.30
Standard deviation	2.48± .08	3.84± .09	2.92± .10	3.68± .10	4.17± .21
Coefficient of variation	34.40±1.31	55.25±1.70	43.39±1.73	50.83±1.72	70.20±5.06

TABLE 8.—*Average plant yields of Marquis and Kota parents, total F_3 hybrids, and the awnleted, segregating, and awned hybrids, by 1.5-gm. frequency classes, at Bozeman, Mont., in 1927*

Yield per plant in grams	Number of plants of—					
	Parents and hybrids			F_3 hybrids by awnedness groups		
	Marquis	Total F_3 hybrids	Kota	Awnleted	Segregating	Awned
0.8		1			1	
2.3		1			0	1
3.8		7			3	4
5.3	2	26		5	13	8
6.8	5	56	4	14	30	12
8.3	5	56	4	24	20	12
9.8		32	2	11	19	2
11.3		12		3	8	1
12.8		3	1		3	
14.3		1			1	
Total plants	12	195	11	57	98	40
Mean yield	7.18±0.21	7.77±0.10	8.44±0.36	8.12±0.13	7.96±0.15	6.80±0.20
Standard deviation	1.08± .15	2.05± .07	1.75± .25	1.49± .09	2.26± .11	1.87± .14
Coefficient of variation	15.04±2.12	26.38± .96	20.73±3.11	18.35±1.20	28.39±1.47	27.50±2.22

A total of 195 F_3 hybrid strains from normal F_2 plants was continued in 1927. Because dwarf plants were present in some of the hybrid rows it seemed best, for reasons stated later, to present the average yield per row on a plant basis. In 1927 the Kota check rows had a higher average plant yield than the Marquis checks. The difference of 1.26 ± 0.42 gm. is three times its probable error, giving odds of about 22 : 1 that the difference is not due to chance. This is the reverse of the results in 1926. The F_3 hybrid rows again were intermediate in yield between the parent checks, and there were several strains that were lower and one that was higher in yield than the extremes of both parents.

Relation of Awnedness to Yield

In the F_2 generation the average yield of the awnleted hybrid plants exceeded by 1.30 ± 0.33 gm. the average yield of the awned plants. There was no significant difference in the variability of the two classes. The difference in yield is due in part to greater shattering among the awned plants. The frequency distribution of the awned plants shows that there is a bunching of the plants in the lower yield classes and that the curve is not normal, as it was for the awnleted class. This apparently was caused by the shattering which occurred.

The data in Table 8 show the average plant yields of F_3 strains in the awnleted, segregating, and awned groups. As in the F_2, the awnleted exceeded the awned strains in yield, even though the awned Kota parent outyielded the awnleted Marquis parent. The difference in average yield between the awnleted and awned F_3 strains is 1.32 ± 0.24 gm., which is statistically significant. As in the F_2 generation, shattering occurred, and again it was much worse in the awned than in the awnleted strains. Shattering estimates taken on a row basis at harvest time show that the awnleted strains shattered 8.25 per cent, whereas the awned rows shattered 14.38 per cent. This difference in shattering tends to increase the difference in yield between the two awnedness groups. Had no shattering occurred, the awnleted strains apparently still would have outyielded the awned, but the difference would not have been so great.

Relation of Presence of Dwarf Plants to Yield

In the F_3 generation there were 106 hybrid strains which had no dwarf plants. These yielded on an average 41.89 ± 0.64 bushels per acre. There were 89 strains which had contained dwarfs, and these yielded 35.31 ± 0.65 bushels per acre. The difference of 6.58 ± 0.91 bushels in favor of the rows without dwarfs is 7.2 times the probable error and is very significant.

In order to discover whether the presence of dwarf plants in the row would permit an increase in the yield per normal plant, the average yield per plant in the row was determined. It was found that the average yield per normal plant in rows without dwarfs was 7.65 ± 0.13 gm., while in rows with dwarfs the average yield per normal plant was 7.91 ± 0.15 gm. The difference of 0.26 ± 0.20 gm. is not significant, as it is only 1.3 times the probable error. This brings out clearly the fact that the reduction in yield is due to the dwarf plants failing to head, as they appear to use the available moisture and plant food to such an extent that the normal plants are unable to produce higher yields.

CRUDE-PROTEIN CONTENT

The crude-protein content of wheat is of economic importance, as premiums are paid for high-protein wheat. The value of wheat for bread making is improved by increasing the protein content.

Clark and Hooker (*5*) have reported the segregation and inheritance of crude-protein content in hybrids between Marquis and Hard Federation wheats under Montana conditions. In that cross Marquis was the high-protein parent. In the present study of inheritance in crosses between Marquis and Kota wheats, Marquis is the low-protein parent.

The crude-protein content of the grain from F_2 plants and parents and of the bulk grain from nursery rows of F_3 strains and parents was determined[3] from a 2-gm. sample of whole kernels. Only single determinations were made because of the limited quantities of grain from single plants. The F_2 data are given in Table 9.

TABLE 9.—*Crude-protein content, by 1 per cent frequency classes, of the Marquis and Kota parents, the total population of F_2 hybrid plants, and the awnleted and awned hybrids, grown at Bozeman, Mont., in 1926*

Crude-protein content (per cent)	Number of plants of—				
	Parents and hybrids			F_2 hybrids by awnedness classes	
	Marquis	Total F_2 hybrid population	Kota	Awnleted	Awned
10.5		3		3	
11.5		13	1	9	4
12.5	10	26	11	22	4
13.5	24	31	20	24	7
14.5	58	34	29	26	8
15.5	35	39	21	31	8
16.5	6	26	38	21	5
17.5		5	14	3	2
18.5		3	6	3	
19.5		1	1	1	
Total plants	133	181	141	143	38
Mean protein	14.52±0.05	14.44±0.09	15.37±0.09	14.44±0.10	14.42±0.18
Standard deviation	.96± .04	1.76± .06	1.65± .07	1.78± .07	1.66± .13
Coefficient of variation	6.61± .27	12.19± .44	10.75± .44	12.33± .50	11.51± .90

Protein data are available from only 181 plants, because in some cases all of the grain was needed for seeding the F_3 rows. Kota had an average protein content of 15.37±0.09 per cent, whereas the Marquis protein content averaged 14.52±0.05 per cent. The average protein content of the F_2 plants was slightly, but not significantly, less than that of Marquis. It will be noticed that Marquis was much less variable than Kota in protein content. The F_2 hybrid plants were much more variable than Marquis and slightly more variable even than Kota. This greater variability of the hybrids over the parents has not been obtained in other studies (*3*, *4*, *5*) for segregation of protein content in wheat crosses.

The F_3 data on hybrid strains and parent check rows in 1927 are shown in Table 10.

[3] The crude-protein tests were made in the nitrogen laboratory of the Bureau of Chemistry and Soils by H. M. Joslin under a cooperative agreement with the Office of Cereal Crops and Diseases, Bureau of Plant Industry.

TABLE 10.—*Crude-protein content, by 0.5 per cent frequency classes, of the Marquis and Kota parents, total population of F_3 hybrid strains, and the awnleted, segregating, and awned hybrids, grown at Bozeman, Mont., in 1927*

Crude-protein content (per cent)	Number of plants of —					
	Parents and hybrids			F_3 hybrids by awnedness groups		
	Marquis	Total F_3 hybrid population	Kota	Awnleted	Segregating	Awned
13.3		2		1	1	
13.8		7		2	5	
14.3		36		16	19	1
14.8	8	29		9	18	2
15.3	2	52	1	16	22	14
15.8	1	49	4	12	25	12
16.3	1	17	4	1	6	10
16.8		3	2		2	1
Total plants	12	195	11	57	98	40
Mean protein	15.09±0.09	15.20±0.03	16.12±0.09	14.98±0.06	15.14±0.05	15.69±0.06
Standard deviation	.48± .07	.72± .02	.44± .06	.66± .04	.73± .04	.52± .04
Coefficient of variation	3.18± .44	4.74± .16	2.73± .39	4.41± .28	4.82± .23	3.31± .25

These data show that Kota averages 1.03 ± 0.13 per cent more protein than Marquis. The mean of all F_3 rows is intermediate between those of the two parents. No strains were obtained showing a higher protein content than the highest Kota check row, but several strains had a lower protein content than the lowest Marquis check row. The hybrids again were more variable in protein content than either parent.

RELATION OF AWNEDNESS TO PROTEIN CONTENT

Table 9 presents the data for protein content of the awnleted and awned classes of F_2 plants. Although the awnleted group showed a greater range of protein content, the averages of the two groups were practically equal.

The F_3 data, as given in Table 10, show that the awned group is significantly higher in protein content than the awnleted, the difference, 0.71 ± 0.08 per cent, being nearly nine times its probable error. The segregating group averages intermediate between the awnleted and awned groups. These data are in general agreement with those for yield, as protein content and yield are usually negatively associated; i. e., as yield increases protein content decreases.

It may be concluded, therefore, that in the Kota×Marquis cross, grown under favorable conditions at Bozeman, Mont., awnleted selections average higher in yield but lower in protein content than do awned selections. While there may be exceptions, this would appear to be the reaction of awnedness under favorable Montana conditions as compared with the opposite reaction under less favorable conditions, as has been found in North Dakota and Minnesota.

RELATION OF PRESENCE OF DWARF PLANTS TO PROTEIN CONTENT

In order to determine what effect, if any, the occurrence of dwarf plants had on protein content of normal plants, the average protein content of the strains with dwarfs and without dwarfs was obtained. There were 106 F_3 strains which had no dwarfs and 89 strains with dwarfs. It was found that the strains with dwarfs had an average protein content of 15.15 ± 0.05 per cent and those without dwarfs had 15.24 ± 0.05 per cent. The difference is only 0.09 ± 0.07 per cent, showing that the presence of dwarfs had no influence on protein content.

CORRELATION OF CHARACTERS

The correlated inheritance of the quantitative characters, the yield and protein content, and the relation between these characters has been studied.

YIELD AND PROTEIN

Data are available on 181 F_2 plants for both plant yield and crude-protein content. The correlation coefficient obtained for yield and protein content on these F_2 plants was negative, $r = -0.124 \pm 0.049$. This coefficient is not large and, as it is only 2.5 times its error, is not significant. This indicates that there was no important relation between the yield and protein content in the F_2 plants of the Kota × Marquis crosses grown at Bozeman, Mont., in 1926.

In 1927 the correlation between the yield and protein content of 195 F_3 strains also was negative, $r = -0.281 \pm 0.044$. This coefficient is hardly important from a plant-breeding standpoint, although it is statistically significant.

It may be concluded that under these Bozeman conditions there was a slight tendency for yield and protein content to be negatively correlated; i. e., as yield increases, protein content decreases, but that it was not of such magnitude as to nullify the effect of selecting for quality on the basis of protein content.

YIELD OF F_2 AND F_3

The coefficient of correlation obtained for yield of 181 F_2 plants with that of the average yield per plant of F_3 rows was positive, $r = 0.186 \pm 0.047$. This is not an important correlation, although mathematically it is significant.

PROTEIN OF F_2 AND F_3

The coefficient of correlation obtained for protein content of 173 F_2 plants and that of the average of F_3 strains was positive, $r = 0.413 \pm 0.043$. This correlation is both significant and important. The correlation surface is given in Table 11.

TABLE 11.—*Correlation between crude-protein content of F_2 plants and that of F_3 strains of Kota × Marquis wheat crosses grown at Bozeman, Mont., in 1926 and 1927*

Crude-protein content of F_2 plants (per cent)	Distribution of F_3 strains by classes for crude-protein content [a] as indicated								
	13.3	13.8	14.3	14.8	15.3	15.8	16.3	16.8	Total
10.5		1	1	1					3
11.5		2	3	3	4	1			13
12.5	1	2	3	2	7	7		2	24
13.5			5	3	10	8	4		30
14.5	1		7	3	14	6	3		34
15.5			7	9	9	9	2	1	37
16.5			3	4	3	11	2		23
17.5						3	2		5
18.5			2		1				3
19.5							1		1
Total plants	2	5	31	25	48	45	14	3	173

[a] $r = 0.413 \pm 0.043$.

The distribution of the data in Table 11 illustrates the relationship which exists between the protein content of F_2 plants and that of F_3 strains. It indicates that in breeding for high protein content, selection of high-protein plants in the segregating F_2 generation offers a promising method of attack.

SUMMARY

This study was undertaken to determine, in crosses between Marquis and Kota wheats, the inheritance of yield and crude-protein content, the genetic factors involved for awnedness and dwarfness, and the effect of awns and dwarfs on the yield and protein content of the hybrid plants and strains. The material was grown under favorable conditions in Montana in 1926 and 1927.

The awnleted Marquis parent had outyielded the awned Kota parent in varietal experiments covering the previous five years under favorable conditions at the Bozeman and Moccasin stations but not under unfavorable conditions at the Havre station. The awned Kota parent had exceeded the awnleted Marquis parent in crude-protein content at all three stations.

Dwarf plants appeared in the F_2 generation in a ratio close to 13 normal to 3 dwarf. In the F_3 generation the normal plants bred true or segregated in the ratio of 7:6. The results were explained on a basis of two genetic factors. Dwarf plants caused a significant difference in acre yield of the F_3 rows, but no difference when computed on a basis of yield per plant.

The awnleted and awned classes segregated in the F_2 generation close to a 3:1 ratio. An attempt was made in F_2 to separate the awnleted class into weakly awnleted and strongly awnleted groups. The weakly awnleted plants bred true to the extent of 91.7 per cent, and the strongly awnleted plants segregated to the extent of 87.9 per cent. The F_2 data, corrected on the basis of F_3 results, were close to a 1:2:1 ratio. Both results showed a single genetic factor difference.

Yields of F_2 and F_3 plants averaged intermediate between those of the parent varieties, although in 1926 Marquis was the higher yielding parent and in 1927 Kota was the higher yielding. The yields of the hybrids were more variable than those of the parents. The yields of awnleted F_2 plants and F_3 strains were significantly higher than those of the awned. Greater shattering of awned than awnleted plants and strains was partly responsible for the difference in yield.

The average of the crude-protein content of the F_2 plants and F_3 strains was not significantly different from that of the low-protein Marquis parent. Plants and strains lower in protein content than the extreme of the parent checks but not higher were obtained. There was no difference in average protein content of awnleted and awned F_2 plants, but the awned F_3 strains were significantly greater in protein content than the awnleted, with the segregating strains averaging intermediate.

It is concluded that in crosses between Kota and Marquis wheats grown under favorable conditions at Bozeman, Mont., awnleted selections average higher than awned selections in yield but lower in protein content.

Yield and crude-protein content were negatively correlated in both the F_2 and the F_3 generations, but in neither case was the co-

efficient sufficiently large to be considered important from a plant-breeding standpoint.

The yield of F_2 plants in 1926 and that of F_3 strains in 1927 was positively correlated, but while the coefficient was significant it was hardly large enough to be important.

The crude-protein content of F_2 plants and F_3 strains was correlated positively, and was both significant and important. The results indicate that in breeding for high-protein content the selection of high-protein plants in the segregating F_2 generation offers a promising method of attack.

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