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A study of correlated inheritance in a certain Avena cross

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Study of Correlated Inheritance in a Certain Avena Cross

By

R. J. GARBER and K. S. QUISENBERRY

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*A Study of Correlated Inheritance in a Certain Avena Cross**

The inheritance of quantitative characters is of particular interest to the plant breeder engaged in an attempt to produce superior economic plants. More detailed information concerning the manner of transmission of size characters in our common crop plants is needed to aid in accomplishing crop improvement. It was with the hope of contributing something to our present knowledge that a number of size inheritance studies in oats were planned a few years ago. The results of two of these studies have been published in recent bulletins of this station.† A review of the literature pertaining to the inheritance of quantitative characters in oats may be found in these bulletins and also in a recent publication of the Pennsylvania Agricultural Experiment Station.‡

The parent plants, a few F_1 plants, and a considerable number of the F_2 and the F_3 generations of *Avena sativa* used for this study were grown in the plant breeding nursery at Morgantown in 1923. The cross was first made in 1921 for the purpose of studying the inheritance of resistance to smut and continued as such for three years, but the smut epidemic failed to materialize, and since the parents of the cross differed with respect to a number of characters, it was decided to use the material for an inheritance study of these characters.

MATERIAL AND METHODS

The parents of the progeny, whose breeding behavior is described in the following pages, were single panicle selections made from the varieties Black Mesdag and Gopher. Black Mesdag is a midseason oat, highly resistant to oat smut, with black seed and stiff culms. It has somewhat broader leaves than Gopher and is inclined to develop fewer culms per plant.

Gopher, a pure line selection made at the Minnesota Agricultural Experiment Station from the variety "Sixty Day," is an early-maturing, white-seeded strain with an exceptionally stiff straw. It has a somewhat coarser appearance than Sixty Day, and also has

*Submitted for publication May, 1926.

†QUISENBERRY, K. S. Correlated Inheritance of Quantitative and Qualitative Characters in Oats. W. Va. Agr. Exp. Sta. Bul. 202. 1925.

‡ODLAND, T. E. The Inheritance of Rachilla Length and Its Relation to Other Characters in a Cross Between *Avena Sativa* and *Avena Orientalis*. W. Va. Agr. Exp. Sta. Bul. 219, April, 1928.

‡NOLL, C. F. Studies of Inheritance of Earliness in Certain *Avena* Crosses. Pa. Agr. Exp. Sta. Bul. 194. 1925.

greater awn development under the environmental conditions at Morgantown. It is one of the highest yielding varieties of oats that have been grown on the Agronomy Farm at Morgantown.

These varieties were crossed in the greenhouse, and in 1921, a small F_1 generation was grown. An F_2 generation was grown in 1922 but no notes were taken on the characters discussed in this bulletin until 1923, when a considerable number of F_2 and F_3 families was available. In addition, a few F_1 plants and the parents, all grown under similar conditions, were also available during this year.

Just previous to the planting of this material, the seed was treated with smut, but, owing apparently to the adverse conditions for the development of the fungus, very few plants of the susceptible parent became infected. In view of this fact it was decided to use the plants for a study of the inheritance of leaf width, number of culms, date of heading, and color of seed in their relation to one another. The study was continued in 1924 when the seed was not treated with smut and somewhat larger F_3 families were grown.

In 1923 the parents and the progeny were grown in rows eight feet long and one foot apart, with 35 seeds spaced approximately three inches apart in each row. It was necessary to fill out some rows with bulk seed, the plants from which were discarded later. The plants growing next to the borders were not considered, owing to the obvious border influence on development. In 1924 the material was grown in rows five feet long and one foot apart, the 25 seeds planted per row being spaced at approximately equal distances. Two individually spaced seeds of the Gopher parent were planted at each end of the rows to prevent border influence on the experimental plants but were pulled and discarded just previous to heading. The parents were grown every twelfth row among the F_3 families in 1923 and in 1924. The parents were also grown with the F_2 generations. In 1923 the parents and F_3 families were grown in single-row plots but in 1924 they were grown in two-row plots.

Practically all the notes were taken in the field. Heading notes were taken every other day and a plant was considered headed when all the spikelets had emerged from the boot on the main culm. Leaf widths were determined by measuring in millimeters the width of the second leaf (from the top down) at the widest part, which is relatively near the juncture of the blade with the sheath. The measurements were taken after the plants were headed, but before the leaves became dry. The number of culms and color of the seed were ascertained at harvest after the plants had matured. Individual plant data

were taken on part of the parents and on the F_1 and F_2 generations grown in 1923 and on all the material grown in 1924. Number of stems and leaf widths were obtained on the F_2 families grown in 1923, but no attempt was made to keep the notes of individual plants separate.

The soil on which the plants were grown was a DeKalb silt loam of medium productivity. It will be shown later that the plot series used in these experiments were not as uniform as was desirable.

INHERITANCE OF DATE OF HEADING

Preliminary Observations

In order to obtain some idea of the number of F_2 plants grown in 1924 necessary to constitute a random sample, the variability of the F_2 families with respect to date of heading was studied. One of these families had 308 individuals and the other had 314. It so happened that one family was grown on an inferior plot and consequently the mean date of heading of the plants on this plot was different from the mean date of heading of the F_2 family on the other plot. For this reason the data from the two families were kept separate.

In Table 1 are shown the frequency distributions of the mean date of heading based on different random samples taken from the F_2 generation. It will be noted that on the average the 16-Family headed somewhat earlier than the 17-Family. In both families, it may be seen that 62 individuals chosen at random constituted a fairly trustworthy sample from which to calculate a mean. In the case of the 16-Family, 30 individuals taken at random gave a fairly trustworthy sample. The mean dates of heading of the ten samples, each made up of 30 individuals, fall into two classes.

TABLE I.—Frequency Distributions for the Mean Dates of Heading Based on Different Samples Taken from the F_2 Generation of Gopher $\times$ Black Mesdag and the Reciprocal Grown in 1924.

Kind of Sample	n	Mean Dates of Heading*						
		7.25	7.75	8.25	8.75	9.25	9.75	10.25
Population, 16-Family /			1					
5th individual	62		4	1				
10th individual	30	2	1	5	2			
15th individual	20	4	4	4	3			
Population, 17-Family						1		
5th individual	62					4	1	
10th individual	30					5	5	
15th individual	20			1	1	4	7	2

*The date of heading of the first F_2 plant was considered as 1, and the mean dates given here are in terms of days.

TABLE 2.—Frequency Distributions for the Standard Deviations of Dates of Heading Based on Different Samples Taken From the F_2 Generation of Gopher $\times$ Black Mesdag and the Reciprocal Crosses in 1924.

Kind of Sample	n	Standard Deviat on of Date of Heading					
		1.5	1.8	2.1	2.4	2.7	3.0
Every 5th individual.....	62		3	5	2		
Every 10th individual.....	30	1	7	5	5	2	
Every 15th individual.....	20	3	10	8	6	1	

The frequency distributions of the standard deviations based on the same random samples as previously discussed are shown in Table 2. Since no appreciable difference was discerned between the distributions from the two families, they were combined in the table. The range of the standard deviations of date of heading of the ten random samples, each made up of 62 individuals, was from 1.8 to 2.4, inclusive. It is apparent from Table 2 that 20 or 30 individuals were enough to constitute a very trustworthy sample from which to calculate a standard deviation.

There were approximately forty individuals in each F_3 family grown in 1924.

Environmental Influence

Before taking up the discussion of the inheritance of date of heading it may be well to point out the possible non-genetic influence on the development of this character. In 1924 the correlation between the mean date of heading of consecutive plots of the parents grown with the F_3 families was determined and also the correlation between the means of the date of heading of the two different parents grown in adjacent plots. If a marked influence of soil on date of heading existed, the correlation coefficients should show it. The correlation between mean date of heading and number of plants per plot was also determined for each parental plot. The data are presented in Table 3.

TABLE 3.—Correlation Coefficients That Show the Effect of Environment on Date of Heading in the Oat Parents Grown in 1924.

Nature of Correlation	n	r
Between mean dates of heading in consecutive plots of Gopher.....	27	+0.372±0.12
Between mean dates of heading in consecutive plots of Black Mesdag.....	27	+0.429±0.06
Between mean dates of heading of Gopher and of Black Mesdag in adjacent plots.....	31	+0.712±0.00
Between mean dates of heading and number of plants per plot of Gopher.....	31	-0.679±0.85
Between mean dates of heading and number of plants per plot of Black Mesdag.....	31	-0.030±0.02

The correlation coefficient between the mean dates of heading in consecutive plots of Gopher is $+0.372 \pm 0.112$, and in consecutive plots of Black Mesdag $+0.429 \pm 0.106$. These facts and the relatively high correlation ($+0.712 \pm 0.060$) obtained between the mean dates of heading of the two parents growing in adjacent plots indicate that the soil medium in which the plants grew had a rather marked influence on date of heading.

The number of plants per plot in the Gopher parent was negatively correlated (-0.679 ± 0.065) with the date of heading but in the Black Mesdag parent no such relationship was found. In this case the correlation (-0.090 ± 0.120) was sensibly zero.

In addition to the environmental factors already mentioned, seasonal time of planting may influence the date of heading. In 1923 the difference between the mean dates of heading for the two parents was about two weeks, whereas in 1924 the difference was approximately one week.

Data In 1923

Individual plant notes were taken on the F_1 and F_2 plants in 1923 only. The mean date of heading of each parental plot was estimated. The approximate mean date of heading of each of the two plots of Gopher growing with the first and second generation plants was June 18 and for each of the two plots of Black Mesdag July 1, an estimated difference between the parents of 13 days. There was no difference between the date of heading of the two F_1 plants of Gopher and Black Mesdag and the four F_1 plants of the reciprocal cross. The mean date of heading of the six F_1 plants was June 16 or approximately the same as the early maturing parent. This is in agreement with the behavior of some of the F_1 generations reported by Noll.*

The F_2 generation showed considerable variability with respect to date of heading as was expected. The frequency distribution is shown in Table 4. The range of date of heading is from the early parent to

TABLE 4.—Frequency Distribution of the Dates of Heading for the F_2 Generation of Gopher $\times$ Black Mesdag and the Reciprocal Grown in 1923.

Name of Strain	Dates of Heading†										
	6/16	6/18	6/20	6/22	6/24	6/26	6/28	6/30	7/2	7/4	n
Gopher $\times$ Black Mesdag & Reciprocal	60	58	29	44	59	116	67	21	0	1	455

†Given as month and day; thus 6/16 means June 16.

*See footnote on page 5.

the late parent and shows clearly that segregation has occurred. It is apparent, too, that there were more F_2 plants with a date of heading similar to that of the early parent (June 18) than there were to that of the late parent (July 1).

Data In 1924

Notes were taken on each individual plant for all the material grown in 1924. The difference between the average date of heading for the two parents was approximately one-half of what it was in 1923 owing, undoubtedly, to environmental influence. The frequency distributions of the F_2 generation and the parents which were grown with it are shown in Table 5. There were 308 F_2 plants of Gopher X Black Mesdag and 314 F_2 plants of the reciprocal cross. The difference between the mean dates of heading of the two F_2 families was 1.51 ± 0.11 , which is significant in the light of its probable error. One of the F_2 families, unfortunately, was planted on an inferior plot which fact probably accounts for the difference obtained.

It is evident from Table 5 that segregation for date of heading occurred in the F_2 generation. The mode of the F_2 generation considering both families together corresponds to the mode of the Gopher parent. The F_2 distributions clearly indicate that earliness is inherited as a dominant character. In 1924 the two parents overlapped somewhat in date of heading. The variability of the late parent, as indicated by the standard deviation, is practically the same as that of the earlier parent. The means for dates of heading of the F_2 families are much nearer to the mean of the Gopher parent than to the mean of the Black Mesdag parent.

That date of heading is a definitely inherited character may be further shown by correlating the date of heading of individual plants with the mean date of heading of their F_3 progeny. This has been done in Table 6. The correlation coefficient obtained was $+0.401 \pm 0.046$, which indicates that there was a tendency for F_2 plants to transmit date of heading to their respective F_3 families.

The frequency distributions of the mean dates of heading of the F_3 families and the parents grown with them are shown in Table 7.

The mean date of heading of each of five of the F_3 families was earlier than the mean date of heading of the earliest plot of Gopher. On the other hand there were four plots of Black Mesdag with mean dates of heading later than the mean date of heading of the latest

TABLE 5.—Frequency Distributions of the Dates of Heading for the Parents, the F₂ Generation of Gopher × Black Mesdag, and the Reciprocal Cross in 1924.

Names of Strains	Dates of Heading*														n	m	σ
	6/28	6/29	6/30	7/1	7/2	7/3	7/4	7/5	7/6	7/7	7/8	7/9	7/10	7/11	7/12	7/13	
Gopher.....			12	27	12	53	8	4	5	1							122 2.45±0.09
Black Mesdag.....										6	22	23	47	0	13	1	112 9.50±0.08
Gopher x Bl. Mes.....	7	10	20	46	25	95	52	6	35	0	9	0	3				308 2.94±0.08
Bl. Mes. x Gopher.....		3	6	18	19	58	87	15	63	7	31	0	5	2			314 4.45±0.08

*Given as month and day; thus 6/28 means June 28.

TABLE 6.—Correlation Between Date of Heading of Individual Plants in and the Mean Date of Heading of Their F_3 Progeny in the Cross Gopher $\times$ Black Mesdag and the Reciprocal.

Date of Heading in F_2	Mean Dates of Heading in F_3											Total
	5	6	7	8	9	10	11	12	13	14	15	
15-16	1		3	10	4		1					
17-18		1	4	5	4	2	2	1				
19-20	1	1	1	1	3	1	1			1		
21-22		1	4	3	1	3	2	1	1			
23-24	1		4	5	3	3		4	2			
25-26		1	5	5	7	7	7	6	2			
27-28			1	2	1	5	2	3	2	1	2	
29-30				1			1	1		1		
1-2												
3-4							1					
Total.....	3	4	22	32	23	21	17	16	7	3	2	1

$$r = +0.401 \pm 0.046$$

TABLE 7.—The Mean Dates of Heading for the F_3 Families and the Parents of the Cross Gopher $\times$ Black Mesdag and the Reciprocal Cross in 1924.

Names of Strains	Mean Dates of Heading*													
	6/29	6/30	7/1	7/2	7/3	7/4	7/5	7/6	7/7	7/8	7/9	7/10	7/11	7/12
Gopher.....			9	15	5	2								
Black Mesdag.....									1	5	17	4	3	1
F_3 Families.....	1	4	10	33	24	22	19	18	12	4	2	1		

*Given as month and day; thus 6/29 means June 29.

family. As in the F_2 generation, the mode of the mean dates of heading of the F_3 families corresponds with the mode of the mean dates of heading of the Gopher parent.

In connection with analyzing the F_3 data it is necessary to know not only the mean date of heading of each F_3 family and of each plot containing the parents, but also something of their relative variability. To obtain such a measure the means and the standard deviations, both the means and standard deviations of each parental plot, with respect to date of heading were calculated. The results are recorded in Table 8.

One would expect about 95.5 percent of the variates of a normal frequency distribution to fall within the range delimited by the mean plus or minus two times the standard deviation ($m \pm 2\sigma$). If such

TABLE 8.—The Means and Standard Deviations of Both the Means and Standard Deviations for Dates of Heading of Each Group of Plots Containing the Parents Grown with the F_3 Progeny in 1924.

Names of Strains	Number of Plots	M of Means	σ of Means	M of S. Devs.	σ of S. Devs.
Gopher.....	31	7.4323	0.8232	1.2726	0.1963
Black Mesdag.....	31	14.6694	0.9341	1.3855	0.2444

It is defined from the data in Table 8 we find that for the Gopher parent the limits of the means are $7.4323 \pm 2 \times 0.8232$ or 5.7859 and 9.0787 and for the Black Mesdag parent the limits are $14.6694 \pm 2 \times 0.9341$ or 12.8012 and 16.5376. In a similar manner the limits of the standard deviations for the Gopher parent are 0.8800 and 1.6652 and for the Black Mesdag parent they are 0.8967 and 1.8743.

In Table 9 the F_3 families are classified according to the foregoing defined limits. While this classification is somewhat arbitrary, it does afford a method of comparing the F_3 families with the parents in regard to the character under discussion.

TABLE 9.—The Frequency Distributions of the Means and Standard Deviations of Dates of Heading for the F_3 Families.

Statistical Constants and Progeny	Limits							Total
(1)	(2)	(3) Gopher	(4)	(5)	(6)	(7) Bl. Mes.	(8)	(9)
Means.....	<	5.7859 9.0787	=	<	<	12.8012 16.5376	=	
Standard Deviations.....	=	0.8800 1.6652	<	=	<	0.8967 1.8743	<	
Families.....	4	49	21	27	40	6	3	150

In column 2 are placed the four F_3 families whose means are less than the lower limit of the means for the Gopher parent but whose standard deviations fall within the limits of the standard deviation of the Gopher parent. Similarly, in column 4, there are 21 F_3 families whose means fall within the limits marked by the Gopher parent but whose standard deviations are greater than those of the Gopher parent and in most cases also greater than those of the Black Mesdag parent. The 27 F_3 families in column 5 had mean dates of heading

intermediate between the upper limit marked by the Gopher parent and the lower limit marked by the Black Mesdag parent. The standard deviations of these F_3 families fell within the limits marked by the Gopher parent. In column 6 are placed the 40 F_3 families whose means were intermediate between the upper and lower limits indicated by the Gopher and Black Mesdag parents respectively, and whose standard deviations were greater than those of the plots of Gopher, and in most cases also greater than those of the plots of Black Mesdag. The three F_3 families placed in column 8 had mean dates of heading similar to Black Mesdag but their standard deviations were somewhat greater.

From Table 9 it is apparent that there were six of the 150 families whose dates of heading were similar to that of the Black Mesdag parent. Both the means and the standard deviations of dates of heading of these six F_3 families fall within the limits indicated by the Black Mesdag parent. If to these are added the three F_3 families whose mean dates of heading were similar to, but whose variability was somewhat greater than that of the plots of Black Mesdag, we obtain 9 F_3 families breeding like the later parent. On a two factor hypothesis, one would expect about this number of F_3 families to breed like the Black Mesdag parent with respect to date of heading. To determine more precisely the breeding nature of this character would require a further study in subsequent generations.

INHERITANCE OF LEAF WIDTH

Preliminary Observations

Before deciding which leaf of the plants to measure for leaf width some preliminary studies were made. In 1923 the first, second, and third leaves (calling the uppermost leaf the first, etc.) of 359 plants of Gopher, 354 plants of Black Mesdag, and all of the F_2 plants were measured for width. The statistical constants of the various measurements made on the parents are shown in Table 10.

There was little absolute difference between the means of the widths of the first and second leaves of Black Mesdag. In the Gopher parent, however, the second leaf was approximately one-third wider than the first leaf. The third leaves of both parents were somewhat narrower on the average than their respective second leaves. The standard deviations of leaf widths of the Black Mesdag parent were somewhat greater than those of the Gopher parent. The variability of leaf width of the first leaf in both parents was high, as indicated by the coefficients of variability. The coefficients also show that there was no much difference between the variability of the second and third leaves of the two parents.

TABLE 10.—Means, Standard Deviations, and Coefficients of Variability for Leaf Widths of the First, Second, and Third Leaves of Gopher and Black Mesdag Oats Grown in 1923.

Names of Strains	n	m			σ			c		
		First Leaf	Second Leaf	Third Leaf	First Leaf	Second Leaf	Third Leaf	First Leaf	Second Leaf	Third Leaf
Gopher P ₁	359	10.65±0.06	13.86±0.06	11.73±0.05	1.62±0.04	1.74±0.04	1.54±0.04	15.21±0.39	12.52±0.32	13.16±0.34
Black Mesdag P ₁	354	21.67±0.13	21.16±0.11	16.94±0.07	3.53±0.0	2.94±0.07	1.93±0.05	16.28±0.42	13.92±0.36	11.41±0.29

Some interesting relations between leaf widths of the first, second and third leaves of the parents and of the F_2 generation are shown in Table 11. The highest correlations were found between the widths of the second and third leaves, the next highest between the widths of the first and second leaves, and the lowest correlations between the first and third leaves.

The correlation coefficient between the widths of the first and third leaves of the Gopher parent is 0.24 ± 0.03 , of the Black Mesdag parent 0.65 ± 0.02 , of the F_2 generation of Gopher $\times$ Black Mesdag 0.55 ± 0.03 , and of the F_2 generation of Black Mesdag $\times$ Gopher 0.48 ± 0.04 , whereas the coefficients between the widths of the second and third leaves are 0.74 ± 0.02 , 0.89 ± 0.01 , 0.79 ± 0.01 , and

TABLE 11.—The Correlation Between Certain Characters of the Parents and of the F_2 Generation of Gopher $\times$ Black Mesdag and the Reciprocal Crosses Grown in 1923.

Names of Strains	Nature of Correlation	n	r
Gopher P_1	Between width of first and second leaves.....	359	0.62 ± 0.02
Black Mesdag P_1	Between width of first and second leaves.....	354	0.85 ± 0.01
Gopher $\times$ Bl. Mes. F_2	Between width of first and second leaves.....	323	0.70 ± 0.02
Bl. Mes. $\times$ Gopher F_2	Between width of first and second leaves.....	132	0.62 ± 0.03
Gopher P_1	Between width of first and third leaves.....	359	0.24 ± 0.03
Black Mesdag P_1	Between width of first and third leaves.....	354	0.65 ± 0.02
Gopher $\times$ Bl. Mes. F_2	Between width of first and third leaves.....	323	0.55 ± 0.03
Bl. Mes. $\times$ Gopher F_2	Between width of first and third leaves.....	132	0.48 ± 0.04
Gopher P_1	Between width of second and third leaves.....	359	0.74 ± 0.02
Black Mesdag P_1	Between width of second and third leaves.....	354	0.89 ± 0.01
Gopher $\times$ Bl. Mes. F_2	Between width of second and third leaves.....	323	0.79 ± 0.01
Bl. Mes. $\times$ Gopher F_2	Between width of second and third leaves.....	132	0.78 ± 0.02

8 ± 0.02 , respectively. It is of interest to note that with respect to y two leaf widths there is in no case a significant difference between e coefficients of the F_2 generations of reciprocal crosses.

In view of the fact that the widths of the first leaves of the plants re more variable than the widths of the second and third leaves, it is decided not to use the first leaf in the inheritance study. The ond leaf rather than the third was finally chosen for this investiga- n as the third leaf dried somewhat earlier and therefore was less orable for measurement in the field.

In connection with a study of the inheritance of a size character h as this, the question of number of plants to grow in each F_3 family ally presents itself. In order to obtain some information on this uestion for the particular problem at hand, the 323 F_2 plants grown 1923 were studied. The problem was to determine the number of F_2 nts necessary to constitute a random sample of the total population. is was done by taking at random every fifth individual of the 323 F_2 f widths and throwing them into a frequency distribution, thus five quency distributions, each made up of 65 individuals, were obtained. a similar manner frequency distributions were made up by taking random every tenth, fifteenth, and twentieth individual of the 323 eaf widths.

The means and standard deviations for all four of these frequency istributions were calculated. The distributions of the means and tandard deviations are shown in Tables 12 and 13, respectively. It is obvious from these tables that at least 65 individuals should be used in er to constitute a random sample that would give a trustworthy rex as to the breeding behavior of leaf width in the F_2 generation. ce in the F_2 generation maximum variability is obtained, it natur- ally follows that each F_3 family should be represented by the mini- m number of individuals that constitutes a random sample. This

TABLE 12.—Frequency Distributions of the Mean Leaf Widths Based on Different Samples Taken From the F_2 Generation of Gopher $\times$ Black Mesdag Grown in 1923.

Kind of Sample	n	Mean Leaf Widths in Millimeters												
		14.5	14.7	14.9	15.1	15.3	15.5	15.7	15.9	16.1	16.3	16.5	16.7	16.9
ot population.....	323						1							
ve 5th individual.....	65				1		1	1	1					
ve 10th individual.....	33	1					3	2	2	1		1		
ve 15th individual.....	22	1				1	3	2		1	1			1
ve 20th individual.....	17		1			2	2		2	2	1			

TABLE 13.—Frequency Distributions of the Standard Deviations of Leaf Widths Based on Different Samples Taken From the F_2 Generation of Gopher $\times$ Black Mesdag Grown in 1923.

Kind of Sample	n	Standard Deviations of Leaf Widths																
		1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3
Total population.....	323										1							
Every 5th individual.....	65								2	1	1	1						
Every 10th individual.....	33				1		1		3		2		2		1			
Every 15th individual.....	22	1			1	1	2		1	1	1		1					
Every 20th individual.....	17					2	2			2		1	2	1				

analysis of the F_2 generation grown in 1923 indicates that the F_3 families grown in 1924 were not large enough. This fact will be shown also in connection with the discussion of the inheritance of leaf width.

Environmental Influence

As in the case of date of heading, leaf width may be influenced by environment and so in 1924 a study was made of the possible effect of soil and of number of plants per row on the development of leaf width. The correlation coefficients between the means of leaf widths of consecutive plots of the parents growing with the F_3 progenies were computed as was also the correlation between the means of the leaf widths of the two parents growing in adjacent plots. The influence of number of plants per plot on mean leaf widths in each of the parents was also studied. The data are presented in Table 14.

TABLE 14.—Correlation Coefficients That Show the Effect of Environment on the Development of Leaf Width in the Oat Parents Grown in 1924

Nature of Correlation	n	r
Between mean leaf widths in consecutive plots of Gopher.....	27	-0.029 ± 0.005
Between mean leaf widths in consecutive plots of Black Mesdag.....	27	$+0.262 \pm 0.005$
Between mean leaf widths of Gopher and of Black Mesdag in adjoining plots.....	31	$+0.490 \pm 0.005$
Between mean leaf widths and number of plants per plot of Gopher.....	31	$+0.039 \pm 0.005$
Between mean leaf widths and number of plants per plot of Black Mesdag.....	31	$+0.199 \pm 0.005$

The correlation coefficients show that in no case, except between mean leaf widths of Gopher and Black Mesdag grown in adjoining plots, was there a significant correlation. The correlation between the mean leaf widths of the adjacent parental plots was $+0.490 \pm 0.005$.

which shows that there was a "place effect" in the development of this character and that the leaf widths of the two parents tended to vary in the same direction. The lack of correlation between the leaf widths of consecutive plots of either parent is probably an indication that the parental plots as checks should have been distributed more frequently throughout the series. The number of plants per plot apparently did not influence the development of the mean leaf widths of either of the parents.

Data in 1923

The leaf width of individual plants of the F_1 , F_2 , and F_3 generations as well as that of the parents was determined in 1923. This character proved to be highly variable and for this reason larger families should have been grown.

The distributions of the leaf widths of the F_1 and F_2 generations, together with those of the parents, all grown in close proximity, are shown in Table 15.

The data in Table 15 show that the parents differed considerably with respect to leaf width. The mean leaf width of the six F_1 plants was intermediate between the parents but it was somewhat nearer to the mean leaf width of Black Mesdag than to that of Gopher. The F_2 distribution had a lower range than the Gopher parent but did not reach the upper range of Black Mesdag. The mean leaf width of the F_2 generation was somewhat nearer to the mean leaf width of Gopher than it was to that of Black Mesdag. The standard deviation of leaf width of the Black Mesdag parent was almost as great as that of the F_2 generation; the relative variability of the latter, however, was somewhat greater.

The data for the F_3 families together with those for the parents that were grown with them are shown in Table 16. This table shows the distribution of the mean leaf width of each F_3 family and, for comparison, the distributions of the mean leaf widths of the parental plots. It is obvious from the table that the parental plots differed considerably with respect to mean leaf width and that the parental types were recovered in F_3 . There were four F_3 families with mean leaf widths slightly below the plot of Gopher with the lowest mean leaf width. On the other hand the six F_3 families with the highest mean leaf widths were considerably below the plots of Black Mesdag with the higher mean leaf widths. There were only seven of the 139 F_3 families within the range of the mean leaf widths of the plots of Black Mesdag.

It has been previously mentioned that leaf width was a variable character. This was brought out in the 1923 data when an attempt was made to show the relative variability of the parental plots as compared with the several F_3 families. The coefficients of variability were calculated for this purpose. The distributions of the coefficients for the parental plots and the F_3 families are shown in Table 17. It is evident that the range of variability for the Black Mesdag parent is almost as great as that for the F_3 families. In view of this situation it was not thought worth while to analyze the data further for relative variability.

Data in 1924

The leaf widths of individual plants of the parents and the F_2 and F_3 generations were determined in 1924. The frequency distributions of the F_2 generation and the parents which were grown with it are shown in Table 18.

In 1924 the mean leaf width of the F_2 generation was intermediate between the means of the leaf widths of the parents. The variability of leaf width of the Black Mesdag parent as measured by the standard deviation was almost as great as that of the F_2 generation. The distributions of leaf widths of the two parents as given in Table 18 are skewed to the left, or toward the narrower leaf widths.

If leaf width is an inherited character, a positive correlation should be obtained between the leaf widths of individual F_2 plants and the mean leaf widths of their respective F_3 progenies. Such a correlation is shown in Table 19. The magnitude of the correlation coefficient ($+0.512 \pm 0.041$) shows that leaf width was definitely transmitted from the F_2 to the F_3 progeny.

In Table 20 are recorded the frequency distributions of the mean leaf width of each F_3 family and for comparison the mean leaf width of each parental plot.

The mean leaf widths of the two parents do not overlap, as shown by the distribution given in Table 20, although the upper limit of Gopher reaches to the lower limit of Black Mesdag. The distribution of the mean leaf widths of the F_3 families simulates somewhat a normal frequency distribution with a range extending approximately over the combined ranges of the two parents. One F_3 family, namely 16-6-8, had a mean leaf width of only 11.82 ± 0.28 millimeters with a standard deviation of 2.40 ± 0.20 (see Table 33 of appendix). This mean was significantly lower than the lowest mean leaf width of any other F_3 family or any plot of the Gopher parent.

TABLE 17.—Frequency Distributions of the Coefficients of Variability of Leaf Widths for the Parents and F₃ Progenies of Gopher × Black Mesdag and the Reciprocal Grown in 1923.

Names of Strains	Coefficients of Variability																		n
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Gopher Pa.....	1	0	2	3	2	4	1	1	0	1									15
Black Mesdag Pa.....	1	0	0	1	2	2	2	3	0	1	1	1	0	0	1				15
Gopher x Bl. Mes. F ₃ and the Reciprocal.....		1	2	12	10	15	27	17	16	11	6	9	4	3	3	2	0	1	139

TABLE 18. The Frequency Distributions of Leaf Widths for Individual Plants of the F₂ and the Parents of Gopher × Black Mesdag and the Reciprocal Grown in 1924.

Names of Strains	Leaf Widths in Millimeters																						n	m	σ
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			
Gopher.....	1	3	1	1	2	4	13	22	26	26	7	11	5										122	16.88 ± 0.14	2.30 ± 0.10
Black Mesdag.....		1	0	0	0	1	0	6	2	2	3	8	7	10	12	13	20	13	11	3			112	23.04 ± 0.22	3.39 ± 0.15
F ₃ Family.....	1	6	10	9	8	10	19	39	48	55	66	80	61	77	49	36	25	16	5		1	1	622	19.78 ± 0.09	3.51 ± 0.07

TABLE 19.—Correlation Between Leaf Width of Individual Plants in F₂ and the Mean Leaf Width of Their F₃ Progeny of the Cross Gopher × Black Mesdag and the Reciprocal.

Leaf Widths in F ₂	Mean Leaf Widths in F ₃												Total
	12	13	14	15	16	17	18	19	20	21	22	23	
9-10				2									2
11-12					2	3	4		2				11
13-14				4	7	8	8	4		1			32
15-16	1				1	15	14	5	3	3	1		43
17-18					1	5	9	5	9	4	1	2	36
19-20					1	1	1	6	5	5			19
21-22							1		1	1	2		5
23-24								1					1
25-26													0
27-28										1			1
29-30													0
Total.....	1	0	0	6	12	32	37	21	20	15	4	2	150

$r = +0.512 \pm 0.041$

TABLE 20.—Frequency Distributions of the Mean Leaf Widths for the Parents and F₃ Progenies of Gopher × Black Mesdag and the Reciprocal Grown in 1924.

Names of Strains	Mean Leaf Widths in Millimeters													n
	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	
Gopher.....					7	17	6	1						31
Black Mesdag.....									3	4	12	9	3	31
F ₃ Families.....	1				13	19	37	30	16	18	11	5		150

In order to determine the variability of the means and the standard deviations of the parental plots with respect to leaf widths certain calculations were made. For this purpose the mean and standard deviation of the mean leaf widths of each of the two groups of parental plots were determined, and in a similar manner the mean and standard deviation of the standard deviations of each of the two groups of parental plots were computed. The constants obtained are recorded in Table 21.

In a normal frequency distribution 95.5 percent of the variates fall within the range delimited by the mean plus or minus two times the standard deviation. Theoretically, then, we would expect about 95.5 percent of the mean leaf widths of the Gopher plots to fall within the limits of $16.4855 \pm 2 \times 0.7342$ or between 15.0171 and 17.9539.

TABLE 21.—The Means and Standard Deviations of Both the Means and Standard Deviations of Leaf Widths for Each of the Two Groups of Plots Containing the Parents Grown With the F_3 Progeny in 1924.

Names of Strains	Number Plots	M of Means	σ of Means	M of S. Devs.	σ of S. Devs.
Gopher.....	31	16.4855	0.7342	2.0318	0.399
Black Mesdag.....	31	21.5984	1.0141	2.8339	0.469

The limits of these same Gopher plots with respect to standard deviations of leaf widths were between 1.2324 and 2.8312. Likewise the limits of the Black Mesdag plots were between 19.5702 and 23.6266 for the means of leaf widths, and between 1.9547 and 3.8331 for the standard deviations of leaf widths.

It is now possible to classify according to the foregoing defined limits the mean and standard deviation of leaf widths of each family. This has been done in Table 22.

TABLE 22.—The Frequency Distributions of Means and Standard Deviations of Leaf Widths for the F_3 Progenies.

Statistical Constants and Progeny	Limits							Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Means.....	<	Gopher 15.0171 17.9539	<	=	<	Bl. Mes. 19.5702 23.6266	=	
S. Deviations.....	=	1.2324 2.8312	=	<	<	1.9547 3.8331	<	
F_3 Family.....	1	59	27	11	13	37	2	150

In column 2 of Table 22 is placed one F_3 family which had a lower mean leaf width than any Gopher plot and whose standard deviation fell within the limits marked by the Gopher parent. This family has already been discussed. There were 59 F_3 families (column 3) which bred similar to the Gopher parent with respect to both means and standard deviations of leaf widths. In column 4 are placed 27 F_3 families whose standard deviations of leaf widths fell within the limit marked by the Gopher parent but whose mean leaf widths were between the upper and lower limits of the Gopher and Black Mesdag parents, respectively. Eleven F_3 families had mean leaf widths which

all within the limits indicated by the Gopher parent but their standard deviations were greater than that of the Gopher parent and in some cases greater than that of the Black Mesdag parent. The 13 F_3 families with mean leaf widths between the upper limit of the Gopher parent and the lower limit of the other parent are recorded in column 6. The standard deviations of leaf width of these families were outside the limits of the Gopher parent and in some cases also outside the limits of the Black Mesdag parents. There were 37 F_3 families which bred in a manner similar to that of the Black Mesdag parent with respect to means and standard deviations of leaf width. Two of the 150 F_3 families had mean leaf widths which fell within the limits indicated by Black Mesdag but they had standard deviations that fell outside the limits marked by this parent.

Considering all the data on leaf width, it is apparent that this character is a variable one and for purposes of making a more exact analysis of its inheritance larger F_3 families should have been grown. For such a study it would be highly desirable to carry the analysis through the F_4 and subsequent generations. The data presented, however, do seem to justify the conclusion that leaf width is a definitely inherited character and that the manner of its inheritance is dependent upon more than one factor difference.

INHERITANCE OF NUMBER OF CULMS

The inheritance of number of culms was studied in 1923 only, as in 1924 the difference between the two parents with respect to this character was not clearly defined, owing largely to seasonal influence. In 1923 the mean number of culms of 443 Gopher plants was 12 ± 0.11 and of 381 Black Mesdag plants was 4.45 ± 0.08 . In 1924 the mean number of culms of 328 Gopher plants was 3.16 ± 0.04 and of 301 Black Mesdag plants 2.36 ± 0.03 .

The frequency distributions of number of culms of the F_3 plants and the parents which were grown with them in 1923 are shown in Table 23.

It may be noted that there are 68 and 62 plants of Gopher and Black Mesdag, respectively, reported as growing with the F_2 generation in 1923, whereas in Table 15, in connection with the leaf width study, there were but 49 plants of each parent reported. The reason for the smaller number of plants in the latter case is that in 1923 only those parental plants were measured for leaf width which had three upper leaves whose width could be determined. If the lower leaf had withered the plant was eliminated.

TABLE 23.—Frequency Distributions of Number of Culms of Individual Plants for the F_2 and the Parents of Gopher $\times$ Black Mesdag and the Reciprocal Grown in 1923.

Names of Strains	Number of Culms																	n	m	σ
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			
Gopher.....	1	0	11	9	5	9	9	5	5	3	4	2	3	2				68	6.79 ± 0.26	3.19 ± 0.18
Black Mesdag.....	4	9	12	11	10	5	2	5	1	1	0	1	1					62	4.52 ± 0.22	2.54 ± 0.15
F_2 Family.....	5	14	29	60	73	77	45	53	41	24	9	8	9	5	1	1	1	455	6.52 ± 0.09	2.73 ± 0.06

TABLE 24.—Frequency Distributions of the Mean Number of Culms for the Parents and F_3 Progenies of Gopher $\times$ Black Mesdag and the Reciprocal Grown in 1923.

Names of Strains	Mean Number of Culms																	n	m	σ
	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10.25	10.75	11.25			
Gopher.....					1	1	3	4	4	3	0	0	2	0	0	0	0			
Black Mesdag.....	2	4	3	5	0	2	1													1
F_3 Families.....			10	17	21	25	34	19	10	4	3	4								

It may be seen from Table 23 that the modes of the distributions of the number of culms in the two parents correspond, although there were relatively few plants of Black Mesdag with a large number of culms. The means of the number of culms of Gopher and Black Mesdag were 6.79 ± 0.26 and 4.52 ± 0.22 , respectively, whereas, the mean number of culms of the F_2 generation was 6.52 ± 0.09 . The behavior of the F_2 generation seems to indicate that a high number of culms was inherited as a dominant character. It is apparent, too, that the number of culms was a variable character and one that was probably influenced considerably by environment.

That the number of culms is an inherited character, is more clearly shown by the data obtained from the F_3 families. In Table 24 the frequency distributions of the mean number of culms of the F_3 families and the parents which were grown with them are shown. It is obvious that some of the F_3 families bred like the Gopher parent with respect to mean number of culms and other F_3 families like the Black Mesdag parent.

INHERITANCE OF COLOR OF SEED

The Gopher parent of the oat crosses discussed in this bulletin had white seed and the Black Mesdag had black seed. The seeds of the F_1 plants were black but not quite of the same intensity as the seed of the black parent. Of the 455 F_2 plants grown in 1923, 355 had black seed and 100 had white seed. The deviation from expectation on a monohybrid basis was 13.7 ± 6.2 . In 1924 there were 622 F_2 individuals, of which 483 were black-seeded and 139 were white-seeded plants. In this case the deviation from monohybrid expectation was 5 ± 7.3 .

Additional evidence concerning the inheritance of seed color in this oat cross may be obtained from the F_3 generation grown in 1924. Of all there were 150 F_3 families grown during this year. Of this number 40 bred true for black seed, 79 segregated for seed color, and 31 bred true for white seed. This result is in fairly close agreement with expectation, on the assumption that the parents differed in regard to seed color by a single factor.

INTERRELATION OF HERITABLE CHARACTERS

The relation of one character to another is of importance. If two characters are closely linked in their inheritance, and it is desirable to break this linkage, it is necessary to grow a greater number of plants than is the case if the two characters are independent in

their inheritance. A study of the relation in inheritance of the four characters herein considered was made.

Seed Color and Other Characters

In Table 25 are presented the data based on the F_2 generation grown in 1923 which bring out the relationships between color of seed and the other three characters. The reciprocals, although no difference was observed between them, have been kept separate in this table.

The difference between the mean dates of heading for the black-seeded and the white-seeded F_2 plants of Gopher $\times$ Black Mesdag was 2.34 ± 0.35 , and of Black Mesdag $\times$ Gopher, 1.21 ± 0.57 , both instances being in favor of white-seeded plants. The former difference is significant in the light of its probable error, but the latter is not. Since the black-seeded parent was also the later parent, the significant difference obtained was certainly not due to close genetic linkage.

With respect to mean number of culms the black-seeded and white-seeded F_2 plants did not differ significantly from one another in either the Gopher $\times$ Black Mesdag or the reciprocal cross.

The F_2 plants with black seed of Gopher $\times$ Black Mesdag had mean leaf width of 15.39 ± 0.11 , whereas the plants with white seed had a mean leaf width of 16.69 ± 0.20 . The difference of 1.30 ± 0.1 between these means is more than five times its probable error. The difference between the means of leaf width of the black-seeded and white-seeded F_2 plants of Black Mesdag $\times$ Gopher is not significant. Black seeds and wide leaves were associated in one of the parents in this cross so it is apparent that there is no evidence of linkage here.

The data obtained from the F_2 generations grown in 1924 are recorded in Table 26. Here again there is no evidence of a genetic linkage between the several character pairs as they entered the cross. In the Black Mesdag parent, black seed was associated with late maturity, a small number of culms, and wide leaves, as contrasted with the Gopher parent in which white seed was associated with early maturity, a large number of culms, and narrow leaves. In view of the evidence presented, it may be concluded that color of seed is not linked in inheritance with any of the other characters studied in this investigation.

Leaf Width and Number of Culms

The relation in inheritance of leaf width to number of culms was studied by determining the degree of correlation between these characters in the F_2 generation as compared with the parents. Unfortunately, the relation between these two characters was not determined.

Width—in the F_2 Generation of Gopher $\times$ Black Mesdag and the Reciprocal Grown in 1923.

Names of Strains	Color of Seed	Dates of Heading*										n	m					
		6/16	6/18	6/20	6/22	6/24	6/26	6/28	6/30	7/2	7/4							
Gopher x Bl. Mes. F ₂ ..	Black	37	38	20	26	32	59	31	8	0	1	252	22.59±0.19					
Gopher x Bl. Mes. F ₂ ..	White	4	4	3	6	9	23	16	6			71	24.93±0.30					
Bl. Mes. x Gopher F ₂ ..	Black	16	14	5	9	17	20	16	6			103	22.93±0.30					
Bl. Mes. x Gopher F ₂ ..	White	3	2	1	3	1	14	4	1			29	24.14±0.49					
Number of Culms																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Gopher x Bl. Mes. F ₂ ..	Black	2	6	22	32	38	43	29	25	26	12	4	5	4	3	0	1	252
Gopher x Bl. Mes. F ₂ ..	White	1	2	4	14	10	11	5	10	4	5	1	1	1	1	1		71
Bl. Mes. x Gopher F ₂ ..	Black	2	4	3	11	17	18	8	17	7	5	4	2	3	1	0	0	103
Bl. Mes. x Gopher F ₂ ..	White		2	0	3	8	5	3	1	4	2	0	0	1				29
Widths of Leaves in Millimeters																		
		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Gopher x Bl. Mes. F ₂ ..	Black	1	5	5	22	30	31	40	40	24	18	22	9	4	1			252
Gopher x Bl. Mes. F ₂ ..	White			1	3	1	9	11	8	12	7	10	5	2	2			71
Bl. Mes. x Gopher F ₂ ..	Black		1	0	5	8	18	19	12	16	11	9	0	2	0	1	1	103
Bl. Mes. x Gopher F ₂ ..	White				1	1	1	1	8	7	4	3	0	1				29

*Given as month and day; thus 6/16 means June 16.

for the parents in 1923, but it was determined for them in 1924. The results are tabulated in Table 27.

TABLE 27.—The Correlation Between Leaf Width and Number of Culms in the F_2 Generation of Gopher $\times$ Black Mesdag and the Reciprocal as Compared with the Parents.

Names of Strains	Year Grown	n	r
Gopher $\times$ Black Mesdag F_2	1923	323	$+0.30 \pm 0.03$
Black Mesdag $\times$ Gopher F_2	1923	132	$+0.24 \pm 0.06$
Gopher $\times$ Black Mesdag F_2	1924	308	$+0.41 \pm 0.03$
Black Mesdag $\times$ Gopher F_2	1924	314	$+0.41 \pm 0.03$
Gopher P_1	1924	328	$+0.53 \pm 0.03$
Black Mesdag P_1	1924	301	$+0.47 \pm 0.03$

From the last column of Table 27, it is obvious that there is a positive correlation between leaf width and number of culms both in the F_2 generations and the parents. Considering only the plants that were grown in 1924, we find that the magnitude of the coefficients of correlation between leaf width and number of culms in the reciprocal F_2 generations is identical and that the magnitude of the coefficients for these same characters in the parents is somewhat greater although not significantly so. In 1923 the correlation between leaf width and number of culms was not as marked as in 1924. The foregoing correlations are somatic and not genetic since broad leaves and few culms, and narrow leaves and many culms were associated in the parents.

Leaf Width and Date of Heading

The relation in inheritance between leaf width and date of heading was also studied by means of correlation. In the parents broad leaves were associated with late maturity and narrow leaves with early maturity. In Table 28 are recorded the correlation coefficients obtained for these characters in the parents of the F_2 generations.

In 1923 the correlation between leaf width and date of heading was sensibly zero in both F_2 crosses, whereas in 1924 there was a slight negative correlation between these two characters in the F_2 generations. The parents which were studied in 1924 only, showed a somewhat higher negative correlation between leaf width and date of heading than did the F_2 generations grown the same year. These data certainly show there was no close linkage between leaf width and date

TABLE 28.—The Correlation Between Leaf Width and Date of Heading in the F_2 Generation of Gopher $\times$ Black Mesdag and the Reciprocal Compared With the Parents.

Names of Strains	Year Grown	n	r
Gopher $\times$ Black Mesdag F_2	1923	323	+0.08 $\pm$ 0.04
Black Mesdag $\times$ Gopher F_2	1923	132	+0.07 $\pm$ 0.06
Gopher $\times$ Black Mesdag F_2	1924	308	-0.15 $\pm$ 0.04
Black Mesdag $\times$ Gopher F_2	1924	314	-0.29 $\pm$ 0.03
Gopher P_1	1924	328	-0.44 $\pm$ 0.03
Black Mesdag P_1	1924	301	-0.50 $\pm$ 0.03

of heading in this oat cross. Environment seems to have influenced the correlation of these characters to some extent as is indicated by the difference obtained between the coefficients for the F_2 generation in 1923 and in 1924.

Date of Heading and Number of Culms

The Gopher parent was earlier in heading and had a relative larger number of culms than the Black Mesdag parent. If these two characters are linked in inheritance one would expect a negative correlation between date of heading and number of culms in the F_2 generation. Such a negative relation was found as is shown in Table 29. Before drawing conclusions based entirely on the F_2 generation however, it is necessary to know something of the relation between

TABLE 29.—The Correlation Between Date of Heading and Number of Culms in the F_2 Generation of Gopher $\times$ Black Mesdag and the Reciprocal as Compared With the Parents.

Names of Strains	Year Grown	n	r
Gopher $\times$ Black Mesdag F_2	1923	323	-0.38 $\pm$ 0.04
Black Mesdag $\times$ Gopher F_2	1923	132	-0.32 $\pm$ 0.05
Gopher $\times$ Black Mesdag F_2	1924	308	-0.20 $\pm$ 0.04
Black Mesdag $\times$ Gopher F_2	1924	314	-0.36 $\pm$ 0.04
Gopher P_1	1924	328	-0.54 $\pm$ 0.04
Black Mesdag P_1	1924	301	-0.38 $\pm$ 0.04

these two characters in each parent. Such a study was made in 1924 but not in 1923.

It is obvious from the last column of Table 29 that a negative correlation between date of heading and number of culms was found in the F_2 generations grown in both 1923 and 1924, but it is also evident that the negative correlation between these same characters in the parents was just as marked (in one case more so) as the negative correlations in the F_2 generations grown the same year. Apparently, there is no linkage between date of heading and number of culms.

SUMMARY AND CONCLUSIONS

1.—The F_2 , F_3 , and in some cases the F_1 generations of certain oat crosses Gopher $\times$ Black Mesdag and the reciprocal were studied during two years to determine the inheritance of date of heading, leaf width, number of culms, and color of seed. In all, there were grown in 1923 6 F_1 plants, 455 F_2 plants, and 139 F_3 families, and in 1924 there were grown 622 F_2 plants and 150 F_3 families. The parents were grown at regular intervals among the progeny in both years of the experiment.

2.—Earliness was found to be inherited as a dominant character and some evidence was obtained which indicated that in this particular cross there were at least two factor differences concerned.

3.—Leaf width determined at the widest part of the leaf proved to be a variable character and one that was influenced to a marked degree by environment. On the basis of a preliminary study the second leaf, numbering from the top down, was found to be most satisfactory for measuring. Data are presented to show that leaf width is an inherited character, but the manner of its inheritance was not determined. The distribution obtained in the F_2 generation and the behavior of the F_3 families with respect to leaf width was rather typical of what occurs when a cross is made involving a quantitative character dependent on multiple factors for its expression. One F_3 family grown in 1924 had a mean leaf width significantly less than the mean leaf width of any plot of Gopher, the narrow-leaved parent.

4.—Number of culms, like leaf width, is a character which is greatly influenced by environment. In 1923 the difference between the mean number of culms of Gopher and Black Mesdag was much shown in 1923 show that number of culms is an inherited character. Greater than the difference in 1924. Data on the F_2 and F_3 generations

5.—Black seed color in the cross reported here was found to be dominant to white seed color, and was found to be dependent upon a single factor difference for its inheritance.

6.—No positive evidence of close linkage was found between any two of the four characters studied, namely, date of heading, leaf width, number of culms, and color of seed.

APPENDIX

The planting plan showing the arrangement of the plots on which the F_3 families and the parents were grown in 1924 is indicated in Table 30, and also in Table 31. The end of each series is marked by a heavy line. The plots were numbered consecutively and in one direction only; thus the first plot of the first series was just opposite, and across the alley from, the first plot of the second series. In Table 30 the frequency distributions of date of heading of the F_3 families and the parents grown with them are shown, and the frequency distributions of leaf width for the same plants are given in Table 31.

TABLE 30.—Frequency Distributions of Date of Heading of the F_3 Families and the Parents of Gopher $\times$ Black Mesdag and the Reciprocal Crosses Grown in 1924. The Planting Plan is Indicated by the Arrangement of the Strains.

Names of Strains	Dates of Heading (1 = June 26)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Bl. Mes. P ₁												2	8	9	15	0	6	
Gopher P ₁					8	11	6	15	2									
17-6-26 F ₃			1		6	3	4	17	4	1	3							
17-6-2 F ₃				1		2	1	8	13	2	4	2						
17-6-3 F ₃								4	4	9	21	1		1				
17-6-4 F ₃								2	2	11	14	1	10					
17-6-5 F ₃									1	0	1	5	6	4	16	1	4	1
Bl. Mes. P ₁												5	3	4	17	1	10	1
Gopher P ₁					6	18	5	12	1	1								
17-6-6 F ₃								2		3	8	10	18	2				
17-6-7 F ₃				1	2	4	4	13	11	2	5	1						
17-6-8 F ₃					1	3	0	5	8	4	12	4	6					
17-6-9 F ₃			1	0	4	6	11	20	1									
17-6-10 F ₃						2	2	12	12	7	10	1						
Bl. Mes. P ₁												1	11	2	21	1	6	
Gopher P ₁					7	11	5	15	5									
17-6-11 F ₃						1			4	2	8	6	5				1	
17-6-12 F ₃					1	4	2	7	17	1	11	2						
17-6-13 F ₃					2	1	0	6	20	3	5							
17-6-14 F ₃					2	5	7	19	6	4								
17-6-15 F ₃			1	4	5	12	2	9	1	2	2							
Bl. Mes. P ₁												5	3	1	23	0	3	
Gopher P ₁			1	3	9	19	4	8										
17-6-16 F ₃			3	3	1	6	1	15	9	4								
17-6-17 F ₃			5	6	9	10	3	9										
17-6-18 F ₃				1	2	9	4	13	14	2								
17-6-19 F ₃	2	2	4	9	10	8	2	2										
17-6-30 F ₃									4	13	16	0	9	0	2	1		
Bl. Mes. P ₁												5	15	11	14		6	
Gopher P ₁					2	7	6	25	1									
17-6-27 F ₃						1			9	5	15	1	10		1			
17-6-31 F ₃								1	6	6	6	6	14	1	6			
17-6-23 F ₃				1	4	7	3	26	3	1								
17-6-24 F ₃		1	0	1	4	15	3	19	3									
17-6-25 F ₃					3	9	4	20	2	0	2							
Bl. Mes. P ₁												5	7	4	11	1	2	
Gopher P ₁				1	5	8	2	10	4	5								
17-7-26 F ₃			1	2	5	6	5	19	3	2	1							
17-7-2 F ₃				1	2	5	1	5	15	4	5		3					
17-7-3 F ₃					2	2	1	8	15	0	12	2						
17-7-4 F ₃								2	3	5	9	3	16	21	2	1	2	
17-7-5 F ₃						2	1	3	12	4	12	0	5	0	2	0	0	1

(Continued)

BLE 30.—Continued.

mes of Strains	Dates of Heading (1 = June 26)																		n
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
es. P ₁													13	0	14	1	4	4	36
er P ₁						14	1	23	2										40
6 F _s							1	7	18	3	7		3						39
7 F _s				12	12	19	0	4											47
8 F _s								3	4	6	13	3	14	1					44
9 F _s						3	1	4	9	1	9		8	1	2				38
10 F _s									2	2	3	5	20	1	3	0	1		37
es. P ₁												2	7	3	24	1	2	2	41
er P ₁					3	15	0	15	9	2									44
11 F _s					1	1	0	5	25	4	1								37
12 F _s					2	9	3	19	12	0	1								46
13 F _s								6	9	5	11	1	3	1					36
29 F _s							1	3	14	3	15					2			45
15 F _s				1	4	12	3	17	5										42
es. P ₁												5	11	2	14	2	3		37
er P ₁					2	11	2	16	2	1	1								35
16 F _s					3	3	2	3	18		2								31
17 F _s				1	1	7	2	18	8	0	1								38
18 F _s						7	1	8	18	3	2	1							40
19 F _s						3	1	2	7	4	15	2	4	1					39
20 F _s				1	0	2	1	3	13	2	11	1	4	1	1				40
es. P ₁													3	1	20	2	8	1	35
er P ₁					2	1	9	6	11	10	2	1							42
21 F _s				2	1	8		4	7	2	7	2	4	1					38
27 F _s			1		4	4	0	8	4	1	3		5						30
28 F _s					1	9	0	8	15	0	5	0	2						40
24 F _s					1	3	0	10	14	1	4	0	2	0	2				37
25 F _s					3	8		6	16		1		1	1	1				37
es. P ₁												1	10	0	18	0	5		34
er P ₁					1	16	2	19	3	2									43
26 F _s				1	3	15	5	17	7	1									49
2 F _s								3	9	2	12	2	14	2	1				45
3 F _s			1			6	2	6	26	1	3								45
4 F _s					2	0	8	14	1	5	2								32
5 F _s								3	7	1	9	1	12						33
es. P ₁													2	1	32	1	8		44
er P ₁					1	9	0	17	16	0	2								45
6 F _s								1	9	2	12	4	12	0	1				40
7 F _s					0		1	5	15	6	12	0	1						40
8 F _s					1	1	1	2	12	2	4	2	7	0	1				33
9 F _s			2	1	1	9	7	14	3		2								39
10 F _s			1	2	5	17		11	3	1									40
es. P ₁													13	1	18	1	3	1	37
er P ₁			2	2	6	17	5	10	2	1									45
11 F _s					1	6	5	12	12	4	1								41
12 F _s					4	10	4	14	11	1									44
13 F _s					3	6		17	17	1									44
14 F _s				4	6	15	2	8	3		2								40
15 F _s						1	2	4	20	4	8	2	3						44

(Continued)

TABLE 30.—Continued.

Names of Strains	Dates of Heading (1 = June 26)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Bl. Mes. P ₁												7	21	3	6	1	1	
Gopher P ₁					1	28	6	10										
17-8-16 F _s						1		1	1	6	3	3	14	2	4	0	5	1
17-8-17 F _s			1	2		8	5	10	16		1							
17-8-18 F _s						2		7	16	2	11	3						
17-8-27 F _s									3	2	2	3	13	2	9	0	1	3
17-8-28 F _s											6	1	15	3	11		1	1
Bl. Mes. P ₁													2		9	1	19	5
Gopher P ₁						4		10	17	2	1	2						
17-8-21 F _s									9	1	14		6	3	2	1		
17-8-22 F _s									1	4	11		15		3		1	
17-8-23 F _s						2	0	1	8	2	10		11				1	
17-8-24 F _s					4	6	5	10	18	0	1						1	
17-8-25 F _s					1	2	3	5	15	1	6	1	3					
Bl. Mes. P ₁														3	11	4	17	3
Gopher P ₁							1	7	23	2	2	1						
16-6-26 F _s			4	6	11	9	2	11	1	1	1							
16-6-2 F _s									3	5	14	1	15	1				
16-6-3 F _s						4		10	23	1								
16-6-4 F _s					1	2	0	6	18	3	5							
16-6-5 F _s						1			2	2	12	8	14		4			
Bl. Mes. P ₁													5	2	11	2	8	1
Gopher P ₁					1	5	5	4	23	0	2							
16-6-6 F _s			2	0	4	13	0	9	5									
16-6-7 F _s					2	1	3	6	26	3	4	1						
16-6-8 F _s			2		2	3	3	5	8	0	3	0	5	1	1			
16-6-9 F _s									6	0	6	4	14		5	1		
16-6-10 F _s						5		3	7	1	2		2					
Bl. Mes. P ₁													1	11	2	18		4
Gopher P ₁					1	11	6	14	6	3								
16-6-11 F _s								2	1	4	10	4	15			1		
16-6-12 F _s								2	4	8	16	0	7					
16-6-13 F _s						1		8	19	1	2		5			2		
16-6-27 F _s					2	5	3	4	15	1	5	1	6					
16-6-15 F _s					1	12	2	11	13	0	1							
Bl. Mes. P ₁												2	22	1	4	1	2	3
Gopher P ₁					7	19		11	3	1								
16-6-16 F _s						2		5	18	1	6	2	4	1				
16-6-28 F _s					1	4		11	15	1	7	1	4	1				
16-6-18 F _s										1	2	7	9	1	16	5		
16-6-19 F _s					1	5	3	11	10	1		1	1		2			
16-6-20 F _s							1	1	14	1	7	1	9	1		1		
Bl. Mes. P ₁													8	3	20	0	8	1
Gopher P ₁						12	7	11	11	3	1							
16-6-21 F _s			1	0	0	1	1	7	13	4	7	1	7					
16-6-22 F _s						4	1	1	14	7	12		4					
16-6-23 F _s					3	12			14	11	3							
16-6-29 F _s					3	9	4	16	12	0	2							
16-6-25 F _s								7	6	5	11	2	6		2			

(Continued)

TABLE 30.—Continued.

Names of Strains	Dates of Heading (1 = June 26)																		n
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Mes. P ₁												3	8	3	21		7		42
Other P ₁			1		4	9	2	15	13										44
7-26 F _s											6	10	24	0	1				41
7-2 F _s						4	0	5	12	5	6		8						40
7-3 F _s			4	5	3	18	3	8		1									42
7-4 F _s					11	12	8	14	2										47
7-5 F _s					3	7	7	18	10	1									46
Mes. P ₁											5	12	16	0	7				40
Other P ₁					2	17	8	15	1	1									44
7-6 F _s			3	1	3	10	3	22	3										45
7-7 F _s			7	2	11	21	1	1											43
7-8 F _s					2	13	6	10	14										45
7-9 F _s									1	2	4	11	22						40
7-10 F _s							6	17	16	1	1								41
Mes. P ₁													11	1	16		5	6	39
Other P ₁						2	1	5	17		6								31
7-11 F _s									3		1	4	14	1	3	0	2	2	30
7-12 F _s									1	1	5	7	19	0	2				35
7-13 F _s												2	2	5	18	1	5	8	41
7-14 F _s					3	0	2	5	3	7	3	4			2				29
7-15 F _s									5	1	16	1	9		3				35
Mes. P ₁																4	14	17	35
Other P ₁						1		6	15	2	2		2						28
7-16 F _s								2	2	1	9	3	11	1	3				32
7-17 F _s					4	15	2	9	8		4								42
7-18 F _s								4	15		11	4	7		2				43
7-19 F _s										2	6	9	12		6	3			38
7-20 F _s						2	4	7	14		6	3	2			1			39
Mes. P ₁												1	9	2	23				35
Other P ₁					2	16	3	17	1	1									40
7-21 F _s							1	4	6		8	2	16			3			40
7-22 F _s								3	6	1	6	16	11		2				45
7-23 F _s								11	9	2	14	1	6						43
7-24 F _s				2	2	25	8		5										42
7-25 F _s						1		4	11	4	14	1	6						41
Mes. P ₁											2	5	12	5	11		1	2	38
Other P ₁						9	7	13	5		5								39
7-26 F _s									2	2	3	7	14		3	4			35
7-2 F _s								1	3	2	9	10	16						41
7-3 F _s					1	10	2	16	13	1	3								46
7-4 F _s							1	15	16	1	4	2	4						43
7-5 F _s								4	2	1	6	7	13						33
Mes. P ₁											3	9	9	0	10	1			32
Other P ₁			1	1	5	21	5	12											45
7-6 F _s					1	3		12		6	5								39
7-7 F _s				1	3	7	5	12	11		1								40
7-8 F _s					1	19	3	13	6	1									43
7-9 F _s	1		2	1	3	14	6	16	1										44
7-10 F _s					1	4	3	11	17	2	2								40

(Continued)

Names of Strains	Leaf Widths in Millimeters																										
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	n	
Bl. Mes. P ₁									2	2	0	0	5	6	3	4	2	9	4	3							40
Gopher P ₁							1	4	7	10	8	4	5	3													42
17-6-26 F ₃			1	0	1		4	1	6	3	12	6	0	2	2	0	1										39
17-6-2 F ₃							2	0	1	1	4	1	3	4	6	8	2	1									33
17-6-3 F ₃								1	1	0	2	3	3	5	6	5	9	7	3	1	0	0	1				47
17-6-4 F ₃					1	1	0	1	0	1	0	2	2	4	5	3	5	5	2	5	2	0	1				40
17-6-5 F ₃			1	0	1	1	1	1	3	6	1	3	7	4	7	2	0	1	0	0	0	0	1				39
Bl. Mes. P ₁									2	0	1	3	6	5	5	5	4	2	4	3	1						41
Gopher P ₁							4	2	6	10	5	10	5	1													43
17-6-6 F ₃			1	0	5		2	2	8	8	9	4	1	2	0	0	0	1									43
17-6-7 F ₃					1	0	0	4	1	3	4	5	4	6	4	7	1	2	1		1						43
17-6-8 F ₃					1	0	3	1	7	0	5	2	9	6	5	2	0	2				1					43
17-6-9 F ₃						1	1	1	1	2	3	7	9	9	4	3	0	3	0	0	1						43
17-6-10 F ₃					1	1	1	0	1	4	3	3	6	9	6	4	4	2	1								46
Bl. Mes. P ₁									1	0	2	3	3	7	7	5	5	5	2	0	1	1					42
Gopher P ₁		1	1	0	0	1	3	2	12	7	8	5	2	1													43
17-6-11 F ₃			1	0	1	2	1	2	4	5	2	5	1	2	0	1											27
17-6-12 F ₃					1	1	2	5	4	6	12	4	4	2	3	1											45
17-6-13 F ₃							1	0	4	1	4	3	6	2	7	2	2	5									37
17-6-14 F ₃								1	3	5	6	5	7	8	3	3	2										43
17-6-15 F ₃			2	1	0	1	1	3	5	9	8	2	5	1	1												38
Bl. Mes. P ₁									1	1	0	3	1	2	5	4	7	4	4	1	2						35
Gopher P ₁							2	7	5	9	8	5	5	1	2												44
17-6-16 F ₃					2	0	0	0	3	5	6	10	3	4	1	3	2	1	1	0	0	0	0	0	1		42
17-6-17 F ₃					1	1	4	1	5	4	10	6	4	1	5												42
17-6-18 F ₃					1	1	6	6	16	5	6	2															45
17-6-19 F ₃	1	1	1	0	1	1	0	4	9	10	3	3	5	1	1	1	5	6	3	1	0	1					39
17-6-30 F ₃							1	0	1	2	2	3	1	5	5	9	5	6	3	1	0	1					45

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