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A Study of Methods in Barley Breeding[1]

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CONTENTS

INTRODUCTION

An analysis of the yields of 5,842 plant selections made from the progenies of 379 barley crosses is presented in this bulletin. The crosses were all definite matings in a series planned with several objectives in mind. The 28 parents were chosen not only because they had given some indication of qualities that might be useful in breeding superior barleys but also because they would afford a skeleton survey of both the large collection of barleys in the Division of Cereal Crops and Diseases and of the geographical sources of useful types. In addition to the study of these major and several minor problems of varieties, the methods of conducting the experiment were designed to gain information on two ways of handling hybrid progenies. The procedure is most easily presented by narrating the origin of the experiment and reciting the problems that arose.

The writers were confessedly feeling their way because of doubts as to the best methods of procedure. The place of backcrossing in barley breeding is slowly being defined. On the other hand, it was felt that the field of free segregation had not been adequately explored. Many commercial sorts had come from simple crosses followed by selection, but this method also had obvious limitations. The writers have made hundreds of crosses at various times over a period of years, but always there was a lurking feeling that some other cross might have been better. There was little known about the value of varieties as parents and there were too many to choose from. Not only were our commercial sorts available for the experiment, but the Division also maintains a large collection of introductions for breeding purposes. This collection had not been widely used in the making of hybrids, except as a source from which to satisfy specific needs such as disease resistance or genetic characters. Many of these introduc-

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tions are of unquestioned superiority in this or that little mountain valley or oasis of Asia or Africa where they were collected. What this superiority means to the breeder can be determined only after years of effort and for only a few varieties at a time, but here was an opportunity to include at least a sample of this collection.

Once made, the unusually large number of hybrids offered an opportunity to study methods of handling. There were numerous options, but it was finally decided to compare a system of pedigree cultures with a composite where all the crosses were mixed together and grown in a field plot.

The combining of so many and so diverse objectives in a single experiment naturally caused difficulty in the presentation of the results. The evidence is so interwoven that references to widely separated tables have been found necessary on most of the major topics. While this is unfortunate from the viewpoint of presentation, the agreement between the results, when approached in so many ways, is gratifying.

Not all of the questions raised have been answered, but on several points the evidence is unusually convincing and there are no contradictions to explain.

Evidence is presented on a number of major and several minor factors in barley breeding. The parents are evaluated as to their own worth, and the significance of their behavior is correlated with their geographical origin and with such facts as may indicate the value of the collection.

An inherent inferiority of six-rowed × two-rowed crosses is pointed out, and the yields of pedigree hybrids carried in bulk are correlated with the yields of the selections from these hybrids. Data are also presented on two ways of handling hybrid populations, and a third method is suggested.

It will be noted that these problems are the problems of the practical breeder. The fundamentals of genetics and plant breeding are the same, but the plant breeder has problems that pertain to his specific objectives. The possibilities of experimental studies in plant breeding have been overshadowed somewhat by the tremendous activity in fundamental genetics, and it is hoped that a little information is here added to the highly important, and certainly not overemphasized, field of experimental plant breeding.

PLAN OF THE EXPERIMENT

Material and Methods

The parent material finally chosen for the experiment consisted of 28 varieties of barley. It was planned to make all the possible 378 combinations among these parents. As explained later, 379 crosses were finally included. Once made, the hybrid progenies were grown for a number of generations in bulk, making use of time to reduce the number of heterozygous types and of natural selection to eliminate the poorer segregates.

There were three steps in the handling of the material that are of major importance in the analyses presented later in this bulletin: (1) The handling of the pedigree crosses, (2) the later classification of the pedigree crosses into yield groups before selections were made, and (3) the growing of a composite bulk of all crosses.

Pedigree Crosses

Each of the 379 crosses was grown at Aberdeen, Idaho, for 7 generations in single 10-foot nursery rows by the bulk method. No plant selections were made until the eighth generation, but the crosses were pedigreed in the sense that their identities were maintained and records were kept, both of identity and yield. Annually, at harvest time, the entire progeny of each cross was threshed in a nursery thresher. A sample was saved from this seed to continue the cross the following year.

Yield Groups

As a basis for determining the number of plant selections to be made from each cross, the 379 crosses were divided into 5 yield groups on the basis of their preselection yields. During the years in which these crosses had been carried individually in bulk without selection some of them had been found to yield much more than others. The only plausible explanation is that the biotypes which constitute the population of the high-yielding combinations are better. High-yielding crosses, therefore, should be better material from which to make selections. Acting on this thought 15 selections were made from the highest-yielding group of crosses. Ten selections were made from the crosses that fell in the next lower group, and 8, 6, and 5 selections respectively were made from those in the 3 low-yielding groups.

Composite

From each of the 379 F_2 nursery rows an equal quantity of seed was taken and mixed to form a composite lot. This seed was grown in a field plot at Aberdeen and carried in bulk through 1934; that is, from each crop enough seed was saved as it came from the thresher to plant a $\frac{1}{20}$-acre plot the following year.

Plant Selections

No plant selections were made until the eighth generation, grown in 1935. In the eighth generation an acre of ground was space-planted. One-half of the plot was devoted to the 379 pedigree crosses, the identities of which were still maintained in the space-planted area. On the other half of the plot, seed from the 1934 field-plot mixture here designated as "composite" was space-planted. At harvesttime the plants from both the beds of pedigree crosses and from the half acre of space-planted composite were pulled singly and examined, and the best ones were saved. As stated under the heading of Yield Groups, the number selected from any specific cross was determined by the yield of the cross in preceding generations. From the composite a number of selections were saved equal to the total number saved from all of the pedigree crosses.

Testing of Selections

In the planting scheme of 1936 the 5,842 selections were grown in comparative yield tests. If 10 selections were planted from cross $a \times b$ they were followed by 10 from the composite. Thus, alternating throughout the planting, there was a total of 2,921 rows from pedigree crosses intermingled with 2,921 rows from the composite lot. Trebi was planted as a check once in every 20 rows. By using beds containing a multiple of 20 rows and placing the first check in row 5, the checks on any one bed fell halfway between those on the adjacent beds.

At harvesttime each row was harvested separately, and the grain was flailed out in a cloth bag. This system, although laborious, prevented both loss and mixtures. The disposal of each row was determined by both yield and quality. Its yield was compared with that of the nearby checks and with the adjacent rows. Some rows with satisfactory yields were discarded because of obviously poor quality. Others of only fair yield were retained because of superior quality. On the whole, however, there was a high positive correlation between yield and quality.

	B	C	D	E
A	2	12	20	10
B		4	18	16
C			6	14
D				8

FIGURE 1.—Numbering system for a complete series of crosses allowing each cross to be planted between its parents with the least possible number of rows.

PLANTING SCHEME

When the 370 crosses were first planted, the writers were carrying many other experiments and economy of land and labor was important. They therefore desired a planting scheme that would place each hybrid between its parents with the least possible number of rows. It may be apparent to others, but the writers struggled mightily before it became apparent to them, that with an odd number of varieties a triangle could be used to arrange the planting list in such a way that only one more parent row is required than there are hybrids in order to place each hybrid between its parent rows. The method of numbering the rows is illustrated in figure 1, which is not a diagram of the planting, but solely an aid in determining a suitable sequence of row numbers. The diagram is used only as a convenience in obtaining the row numbers, the order of which is determined by using the last parent named in each combination as a parent in the cross to be planted next, as follows:

Parent or hybrid:	*Row No.*
a	1
a × *b*	2
b	3
b × *c*	4
c	5
c × *d*	6
d	7
d × *e*	8
e	9
e × *a*	10
a	11

Parent or hybrid:	*Row No.*
a × *c*	12
c	13
c × *e*	14
e	15
e × *b*	16
b	17
b × *d*	18
d	19
d × *a*	20
a	21

The results are not so perfect with 28 parents, particularly when an error or two was involved in carrying out the pattern. However, very few extra rows of parents were required.

The planting list thus obtained not only served its original purpose, but, since the same order of planting was continued throughout the experiment, it had a direct bearing on the validity of the results obtained. It is impossible to find sufficient uniform soil to grow 6,000 rows of grain in a single block. The field used in this experiment is probably one of the best testing fields in the United States, but some parts were better than others. The planting scheme, through pure accident, resulted in a random distribution that was highly effective. With regard to any one character or the progeny of any one parent, the rows concerned were distributed over the whole area in a most satisfactory manner.

Sufficient space is not available to present a diagram of the actual planting. As a sample of the distribution, segregates of which Multan was one parent are found in the following rows: 1–9, 502–508, 515–522, 1197–1204, 1214–1223, 1494–1509, 1526–1531, 1616–1626, 1637–1647, 2418–2422, 2429–2436, 2624–2630, 2637–2642, 2892–2899, 2909–2913, 3349–3354, 3361–3369, 4046–4051, 4058–4066, 4283–4288, 4294–4299, 4871–4876, 4883–4889, 4968–4975, 4984–4992, 5875–5882, and 5892–5899.

Each group of rows includes all the selections from 1 of the 27 Multan crosses. For instance, rows 502 to 508 consist of selections from Multan × Meloy.

Varieties Used as Parents

The 28 parents were chosen by a method which in itself was a compromise between probability and frustration. Europe, Asia, and Africa were divided roughly into regions that offered conspicuous differences of environment. As stated previously, the object was to find new factors of superiority if possible and to combine them if found. It was apparent that the greater the number of parents the larger would be the number of opportunities for fortunate combinations, and the greater the diversity of origin the better would be the sampling of available barleys. Perhaps even more important, if the varieties were well selected the experiment might throw a little light on the usefulness of the extensive collection of barleys in the possession of this Division. This sample for obvious reasons was a pitifully small portion of the whole. The choice of parents was of vital importance, but the bases for choosing were vague. There are no barleys native to the United States. Since they are self-fertilized, the varieties now grown in the United States, with the exception of the American hybrids, are still as representative of the sections from which they came as are the more recent introductions. On the basis that varieties now grown on farms had something that made them superior under American conditions, 11 important commercial varieties and 4 minor ones were chosen as parents. These, in order of listing in table 1, were Orel, Trebi, Flynn, Wisconsin Winter, White Smyrna, Horn, Manchuria, Glabron, Hannchen, Lion, Oderbrucker, Club Mariout, Alpha, Atlas, and Meloy.

TABLE 1.—*Description of the varieties used as parents and the place of their probable origin*

Variety	C. I.[1] No.	Rows	Grain color	Awns or hoods	Rough or smooth awns	Covered or naked caryopsis	Rachilla hairs (long or short)	Origin
		Number						
Multan	3401	6	Blue	Awns	Rough	Covered	Long	India.
Lyallpur	3403	6	do	do	do	do	do	Do.
Orel	351	2	White	do	do	do	do	Soviet Union
Trebi	936	6	Blue	do	do	do	Short	Armenia.
Golden Pheasant	2488	2	White	do	do	do	do	Hybrid (Scotland).
Arequipa	1256	6	Blue	do	do	do	do	Northwest Africa.
Flynn	1311	6	White	do	Smooth	do	Long	Hybrid (Lion × Club Mariout).
Wisconsin Winter	2159	6	White and blue.	do	Rough	do	Short	Balkans.
White Smyrna	910	2	White	do	Semi-smooth.	do	Long	Smyrna.
Horn	926	2	do	do	Rough	do	Short	Northern Europe.
Everest	4105	6	Blue	do	do	Naked	do	Mount Everest.
Manchuria	2330	6	do	do	do	Covered	do	Manchuria.
Glabron	4577	6	White and blue.	do	Smooth	do	Long	Hybrid (Lion × Manchuria) × Manchuria.
Hannchen	531	2	White	do	Rough	do	do	Northern Europe.
Lion	923	6	Black	do	Smooth	do	do	Soviet Union.
Oderbrucker	4666	6	White	do	Rough	do	Short	Northern Europe.
Club Mariout	261	6	do	do	do	do	do	Egypt.
California Mariout	3625	6	Blue	do	do	do	Long	Do.
Alpha	959	2	White	do	do	do	Long and short.	Hybrid (Manchuria × Champion of Vermont).
Atlas	4118	6	Trace of blue.	do	do	do	Short	Northwest Africa.
Han River	206	6	do	do	do	do	do	China.
Sandrel	937	6	White	do	do	do	do	Northwest Africa.
Maison Carré	3387	6	Blue	do	do	do	Long	Do.
Palmella Blue	3609	2	do	do	Semi-smooth.	do	do	Palestine.
Algerian	1179	6	do	do	Rough	do	Short	Northwest Africa.
Good Delta	3801	6	White	do	do	do	Long	Egypt.
Minia	3556	6	do	do	do	do	Short	Do.
Meloy	1176	6	Blue	Hoods		do	do	Hybrid (probably Hooded × Coast).

[1] C. I. refers to Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

There were thus 13 varieties to be selected from the collection, i. e., 13 to be chosen from thousands of potential parents, any one of which might reveal a hidden treasure. The best that could be done was to round out the list with as wide a geographical distribution as possible, using the commercial sorts already selected as a framework. A limited amount of information was available on the general collection so that relatively promising sorts could be utilized. Multan and Lyallpur were chosen from India, for instance, because they had produced good yields in nursery trials in the Southwest. Three strains from Egypt—Minia, Good Delta, and California Mariout—were taken in addition to Club Mariout, already included because of its commercial standing in the United States. One of these new sorts came from the basins around Minia, another from the Delta, and a third from the dry hills of Mariout. This last is here called California Mariout because of its similarity to the commercial variety of that name. Each of the Egyptian barleys had shown some promise in nursery trials. Arequipa, Sandrel, Maison Carré, and Algerian probably originated in what are now the French provinces of northwest Africa. Everest was found high on the slopes of Mount Everest and had shown little of value besides resistance to summer frosts when grown in the United States. Han River, from the valley of that name in China, appeared to be by far the best of the varieties from China proper. It may even have been distributed for farm trial at one time. The description and geographical distribution of the varieties in the completed list are shown in tables 1 and 2.

TABLE 2.—*Average yield of 2,921 selections grouped according to the geographical origin of parent varieties*

Origin	Varieties	Selections	Average yield of selections	Varieties
	Number	*Number*	*Grams*	
Northwest Africa	5	1,194	489.8	Algerian, Arequipa, Atlas, Maison Carré, Sandrel.
Armenia	1	264	488.2	Trebi.
Egypt	4	939	467.3	California Mariout, Club Mariout, Good Delta, Minia.
China	1	214	459.0	Han River.
India	2	378	458.4	Lyallpur, Multan.
Soviet Union	2	392	457.9	Orel, Lion.
Balkans	1	180	454.8	Wisconsin Winter.
East Mediterranean	2	347	445.9	Palmella Blue, White Smyrna.
Mount Everest	1	173	444.7	Everest.
Hybrids	5	994	439.0	Alpha, Flynn, Glabron, Golden Pheasant, Meloy.
North Eurasia	4	767	437.7	Hannchen, Horn, Manchuria. Oderbrucker.

The origins of the 28 varieties are not all a matter of record and, in one or two instances, might be open to question. The source of Sandrel is speculative and based solely on similarities to varieties still growing in north Africa. Actually the plant was isolated from a two-rowed Moravian barley secured from a European seedsman. The variety produces its best yield in the United States on the eastern range of the north-African types and therefore is not quite typical of that group. On the other hand, it is obviously not from northern Europe and is at least Mediterranean in origin. In a case like Atlas the historical inference supports the logical classification. Actually Atlas is a field selection made in California. The California barleys came into Mexico with the Spaniards, and the unrecorded migrations lead logically to north Africa. Most of the varieties, however, trace definitely to their places of origin and are typical of the sorts found in the fields of the respective regions. Six of these varieties were picked up by the senior author at the place of origin. Four of these were plant selections made in ripe fields of standing grain.

From the description of the varieties found in table 1 it will be seen that there are 21 six-rowed and 7 two-rowed barleys. Twenty-two varieties were characterized by rough awns, 3 were smooth, and 2 were semismooth, that is, smooth for the basal one-third of the awn. Meloy was the only hooded variety, and Everest the only naked one. There were about as many white barleys as blue ones. It will be noted that 2 varieties, Glabron and Wisconsin Winter, contained both blue and white kernels. Glabron, so far as known, is quite uniform except for color. The Wisconsin Winter used was probably mixed with another pure line of the same variety. The odd number of 379 crosses is partly due to this mixture. It had been planned to make all the possible combinations among the 28 parents, but the actual number of crosses included was not 378 as planned. One combination, Arequipa × Good Delta, was not a success, so this combination is missing. It was found, too late, that the supposedly pure line of Wisconsin Winter first used actually was mixed with a second winter strain. When this was discovered, the correct type was isolated and most of the crosses involving Wisconsin Winter were remade. By chance Wisconsin Winter × Horn and Wisconsin Winter × White Smyrna were included twice, the winter strain differing slightly in the two matings. This gave a net number of 379 crosses, 209 of which were six-rowed × six-rowed; 149, six-rowed × two-rowed; and 21, two-rowed × two-rowed.

EVALUATION OF THE PARENTS USED

The value of a variety as a parent can be appraised by two distinct series of observations: (1) The average yields of the pedigree crosses before selections were made and (2) the yields obtained in 1936 from the selections themselves.

The yield of the pedigree crosses before making selections is here best indicated by the number of selections made, as the number of selections made from any one cross was determined by the average yields obtained from that cross in the years the unselected progeny was tested. Since each one of the 28 varieties was used in 27 crosses, the total number of selections indicates the yields of 27 crosses over a series of years. The best parents, as judged by these data, are, of course, those with the greatest number of selections, shown in table 3. Parents from the progenies of which more than 210 selections were made were Atlas, Arequipa, Club Mariout, Minia, Flynn, Trebi, Maison Carré, Sandrel, Good Delta, Algerian, and Han River.

TABLE 3.—*Performance of progenies of varieties in 1936, showing number and average yield of selections, number saved, percentage saved, number of crosses with no superior segregates, and number of superior and outstanding selections*

Variety	Average yield (all selections)	Selections made	Selections saved		Crosses with no superior selections	Superior selections	Outstanding selections
	Grams	*Number*	*Number*	*Percent*	*Number*	*Number*	*Number*
Atlas	511.4	260	130	50.0	5	78	34
Arequipa	503.4	233	98	42.1	9	55	20
Club Mariout	498.9	239	105	43.9	9	61	18
Minia	498.0	279	134	48.0	5	71	31
Flynn	492.6	247	127	44.9	9	36	13
Trebi	488.2	264	120	45.5	9	60	31
Maison Carré	487.2	236	97	41.1	8	44	14
Sandrel	480.6	233	110	47.2	10	57	20
Good Delta	478.1	221	82	37.1	10	41	16
California Mariout	465.9	200	62	31.0	16	27	12
Algerian	463.7	232	87	37.5	10	49	18
Orel	459.3	192	33	17.2	16	19	5
Han River	459.0	214	97	45.3	11	34	7
Lyallpur	457.6	176	37	21.0	10	26	7
Lion	456.6	200	72	36.0	16	19	4
Palmella Blue	455.2	157	38	24.2	16	17	4
Wisconsin Winter	454.8	180	53	29.4	10	14	9
Meloy	454.7	181	59	32.6	10	11	1
Multan	454.6	202	56	27.7	15	24	5
Manchuria	449.6	204	55	27.0	15	21	
Everest	444.7	173	27	15.6	15	17	3
Hannchen	441.9	188	36	19.1	17	18	4
White Smyrna	438.3	190	39	20.5	16	21	2
Alpha	430.7	201	27	13.4	20	13	4
Horn	430.6	195	37	19.0	18	23	7
Oderbrucker	427.4	180	41	22.8	16	19	5
Golden Pheasant	400.8	180	35	19.4	25	2	1
Glabron	389.6	185	52	28.1	20	10	3

Selections were made from the 379 crosses in 1935 and tested in 1936. The average yields of all selections tracing to the various parents (table 3) are in surprising agreement with the yields of the unselected rows as indicated by the numbers of selections from them. The varieties producing the higher-yielding segregates are identical with those named above, except that California Mariout replaces Han River. Undoubtedly these 12 varieties were outstanding as parents at Aberdeen.

Before discussing the individual merit of the varieties, it may be best to consider their adaptation. Some of the features are more easily understood when the parents are grouped according to their geographical origin. When the varieties were chosen, it was thought that each might contribute something of value at Aberdeen even though they themselves were not adapted to Idaho conditions. There was a hope of combining two intangible sorts of superiority that might rest on different unknown factors. The results are inconclusive. Occasional matings revealed promise in some ill-adapted varieties, but more often such parents, even those with good records elsewhere, were disappointing. A geographical arrangement, however, does reveal some definite relationship, even though it fails to explain the results.

Actual data are presented in table 2, and the same data are shown graphically in figure 2. Barleys from north Africa, Armenia, and Egypt are about equal as parents. There is a conspicuous interval between the yields of the segregates of these crosses and those from other regions. The drop from the average of the Egyptian parents to that of Han River, from China, the next best, is more than half (28.3 gm.) of the entire range of averages (52.1 gm.) from the best to the poorest parent.

If the geographical distribution is regarded as representing three belts, the result is curious. An inspection of table 2 shows that northwestern Africa and Egypt provided 9 varieties. A middle belt, comprising the Balkans, eastern Mediterranean countries, Armenia, the southern Soviet Union, India, Mount Everest, and China, is represented by 10 varieties. From northern Europe and Manchuria, 4 varieties are included, and there are 5 hybrids, mostly of north European and Manchurian parentage. When ranked by performance of their progeny, the 9 varieties from north Africa and Egypt are all among the best 11 (table 3) of the 28 varieties. One of the 11 is Flynn, which traces to Egypt through one parent. In other words, these African varieties have characters highly desirable at Aberdeen, despite the fact that not one of them is now in commercial cultivation in southern Idaho and none is considered sufficiently promising to be in the present field-plot tests.

The really unique barley, however, is Trebi. It comes from Armenia, where the environment is quite different from that of the African barleys. In its commercial acreage in the United States it overlaps only on its western and southern margins the area where African types are grown. It does not do well in California, the center of culture of the African types. Yet Trebi, as well as the African types, has qualities that cause it to yield well at Aberdeen and, furthermore, it transmits these qualities to its progeny. It is possible that here characteristics not found in the north-African types are being utilized

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to obtain high yields in the same region where characteristics of the north-African barleys result in high yield. The same thing is partly true of Han River in the middle belt. Orel and Lyallpur, also of this group, were barely included in the better half of the parents. Out of the middle belt there are, thus, four varieties, Trebi, Han River, Orel, and Lyallpur, of better than average merit. From northern Europe and Manchuria, and from those hybrids one parent of which was northern, there was no variety of superior merit on the average.

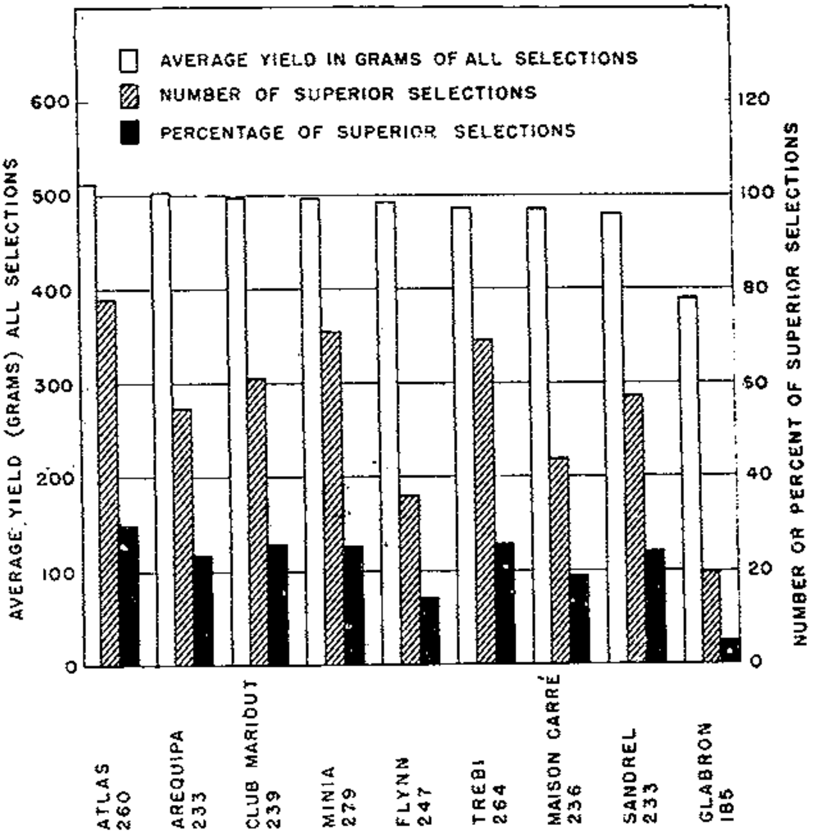

FIGURE 2.—Average yield of all selections, and number and percentage of superior selections from eight superior parents and from one inferior parent.

Flynn, a barley of hybrid origin that was better than average, traces to Africa and the southern Soviet Union.

In all analyses of the data there are definite indications that the average yields of the segregates are a direct index of the value of the parents. In fact, a high average yield of segregates could only be obtained where the individual strains are good. It is always possible, however, that some particular mating may result in an unusually effective combination and that some otherwise ordinary varieties as parents may be responsible for occasional segregates of outstanding merit. Time alone can definitely determine this point. The other analyses presented depend on numbers for their validity. The individual errors are submerged in the averages. Sufficient information is not available to properly evaluate any single selection. The best information at hand is presented in figure 2. It will be noted that Atlas, Club Mariout, Minia, Trebi, and Sandrel produced an unusually high percentage of superior selections. As their average was about the same as that of several other varieties, they must also have been responsible for a greater number of inferior selections than Arequipa, Flynn, and Maison Carré. Arequipa is an interesting parent. The yields of segregates from crosses in which it was a parent differed less than for most of the varieties used. The average yield was high, yet the number of outstanding selections was not exceptional.

To avoid confusion, data from table 3 for only a few of the 28 varieties were used in figure 2. The position of Glabron indicates roughly the point where the various curves would terminate if all varieties were included. Occasional selections, even from the poorer parents, rank high among the outstanding ones. For instance, 2 phenomenally high-yielding strains were isolated from Everest progenies. The hull of Everest segregates, however, is so poor that most of them have been discarded, regardless of yield, as being obviously unsatisfactory to the barley trade.

If the varieties are listed in still another way, a little light is thrown on the possibilities in the collection. In table 4 the varieties are arranged according to their previous records. Sixteen varieties had shown so much promise in plot tests that they had been distributed to farmers and are grown commercially. Seven others had shown sufficient promise in nursery trials to be grown in field plots. Five varieties were included that had never been tested in field plots but that were good representatives from their region of origin, as gaged by nursery yields at some place in the United States. The basis on which the parents are ranked in this table has been broadened to include the number of selections made, which is based on the yields of the crosses previous to 1935, the percentage of crosses saved, and the number of outstanding selections, as well as the average yield of all selections. This affords a better appraisal of the parents, but it does not change the order much. On these bases the same 12 parents are still the better ones. These 12 are so distributed in table 4 that 5 are found among the commercial sorts, 5 have been tested in plots, and 2, Minia and Good Delta, have been grown only in nursery trials. Reduced to percentage of good varieties in each class, there are 31, 71, and 40 percent, respectively. Percentages based on small numbers may mean little, but whether the error was small or large, the fact remains that good parents were found in all three classes. Two conclusions could be drawn from this: (1) It is obvious that the collection may contain better parents than any that have been used; (2) from a different viewpoint it would appear that the varieties in general culture have been well chosen, that most of their genetic factors are specifically adapted to areas where they are now grown, and that usually they are not good parents when used elsewhere. The varieties from the plot test that almost made good averaged a higher percentage of good parents than did commercial varieties not locally adapted.

TABLE 4.—*Varieties arranged according to their previous place in American agriculture, with their average rank as measured by number of selections made, percentage of selections saved, number of outstanding selections, and average yield of all selections*

Average rank of variety previously grown in—		
Nursery, plot test, and commercially	Nursery and plot test	Nursery only
(1) Atlas.	(5) Arequipa.	(2) Minia.
(3) Trebi.	(6) Sandrel.	(10) Good Delta.
(4) Club Mariout.	(8) Maison Carré.	(21) Palmella Blue.
(7) Flynn.	(9) Algerian.	(27) Everest.
(12) California Mariout.[1]	(11) Han River.	(28) Golden Pheasant.
(14) Lion.	(13) Multan.	
(15) Manchuria.	(18) Lyallpur.	
(16) Wisconsin Winter.		
(17) Orel.		
(19) Meloy.		
(20) Horn.		
(22) Hannchen.		
(23) Oderbrucker.		
(24) Alpha.		
(25) Glabron.		
(26) White Smyrna.		

[1] Included because of its similarity to the commercial variety of the same name.

Quality is, of course, important to the breeder and should have a place in evaluating the parents. Inferior quality is discussed in a number of places in this bulletin. High quality was obtained in many crosses and from many parents. Segregates of Atlas and Minia were perhaps of more uniformly good quality than any others. Many segregates of these crosses produced strikingly beautiful grain. Minia, incidentally, would never have been included had it not been for the deliberate effort to find new characters by a geographical survey for possible parents.

Some of the interesting features, however, had to do with neither yield nor quality. In such a large group of hybrids, it is to be expected that abnormal forms would appear. However, the number of these was much greater than might have been expected. Most of the individual plants on the acre of land space-planted in 1935 for the purpose of making selections were very good. There was, however, a sort of undergrowth of shortened unusual types that was visible throughout the field. This undergrowth was more conspicuous in the composite lot, but in that lot the parentage was unknown. From the characters involved and from observations on the 379 hybrid populations kept separate, it was evident that Lyallpur entered into the parentage of many of the freaks. Everest and Multan also made sizable contributions.

A number of wholly new types were found. Another was isolated in which there was an extreme type of dwarfing. The most interesting form came from a cross of Meloy on Palmella Blue. Meloy is a six-rowed hooded barley, and the other parent is a two-rowed awned sort. One of the segregates from this cross was two-rowed with hoods on the end of the lemmas where they would be naturally expected, but the lemmas of many of the kernels also produced two awnlike projections lateral to the hood. When the selection was grown at Sacaton in the winter of 1936–37, these projections usually bore hoods. So far as known, this structure is new to barley.

SIX-ROWED × TWO-ROWED CROSSES

There is one discrepancy in the evaluation of the parents that is explained by a further examination of the results. The two-rowed parents did not produce segregates of high average yields. Yet many of the two-rowed varieties were very high yielding sorts at Aberdeen. White Smyrna, Hannchen, Horn, and Orel are well suited to conditions there. An analysis of six-rowed × two-rowed crosses, however, shows these crosses to be strikingly inferior. Although such crosses are easily made and fully fertile, it is evident that some unrecognized incompatibility exists. This is apparent both in the yields previous to selection and in the yields of the selections made. There were 209 six-rowed × six-rowed crosses, 149 six-rowed × two-rowed crosses, and 21 two-rowed × two-rowed crosses available for this study. It will be recalled that the pedigree crosses were grown in bulk for 7 generations before selections were made. Yields were recorded during this period and the 379 crosses were divided according to these preselection yields into yield groups ranging from very low to very high. The percentages of six-rowed × six-rowed, six-rowed × two-rowed, and two-rowed × two-rowed crosses were determined in each of these groups and are shown graphically in figure 3. The lowest-yielding group is composed mostly of six-rowed × two-rowed crosses. The highest-yielding group, on the other hand, consists mostly of six-rowed × six-rowed crosses. The yield curve of the six-rowed × two-rowed crosses is essentially opposite to that of the six-rowed × six-rowed.

These results, while hardly needing confirmation, are in full agreement with the yields of the selections made from these crosses in 1935 and tested in 1936. The actual figures are found in tables 5 and 6. The average yields of all selections from the different kinds of crosses are presented graphically in figure 4. The graph is based on the yields of 2,921 selections. The 961 selections from six-rowed × two-rowed crosses produced an average yield of 428.9 gm. as compared with 482.0 gm. for 1,789 selections from six-rowed × six-rowed crosses. When the figures for the six-rowed × two-rowed segregates are broken down, a mysterious fact becomes apparent. The low yield of the six-rowed segregates might be explained by the small lateral kernels usually produced on six-rowed segregates from six-rowed × two-rowed crosses. Strange to say, however, the two-rowed segregates are depressed more than the six-rowed, as is evident in figure 5 and table 7. The average yield of the two-rowed selections from the six-rowed × two-rowed crosses is amazingly less than that of the two-rowed segregates from the two-rowed × two-rowed crosses. Included in the 961 selections from the six-rowed × two-rowed crosses were 16 selections homozygous for intermedium. They yielded slightly more than the two-rowed segregates but, when added to them, increased the average less than 1 gm.

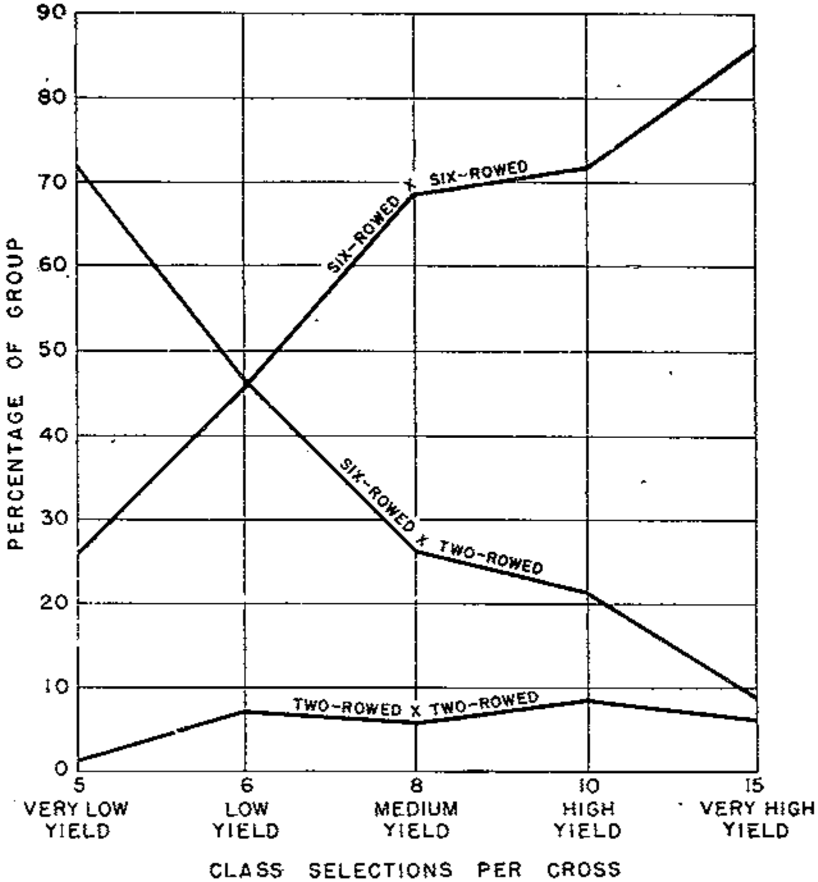

FIGURE 3.—Inferiority of six-rowed × two-rowed crosses shown by placing 379 crosses in 5 successive yield groups according to preselection yields. Relative yields of 149 six-rowed × two-rowed crosses as compared with yields of the 209 six-rowed × six-rowed and the two-rowed × two-rowed crosses are indicated by proportions of such crosses in each group, expressed as percentage of total number in group.

TABLE 5.—*Performance and selection data by groups* [1]

Group No.	Data on performance previous to 1935					
	Selections made from each cross	Crosses	Selections	Crosses		
				Six-rowed × six-rowed	Six-rowed × two-rowed	Two-rowed × two-rowed
	Number	*Number*	*Number*	*Percent*	*Percent*	*Percent*
1	5	77	385	26.0	72.7	1.3
2	6	111	666	46.0	46.8	7.2
3	8	107	855	68.2	26.2	5.6
4	10	49	490	71.4	20.4	8.2
5	15	35	525	85.7	8.6	5.7

[1] 5 selections were made from each cross in group 1, 10 from each cross in group 4, etc.

TABLE 5.—*Performance and selection data by groups*—Continued

Group No.	Data for 1936							
	Average yield (all selections)	Selections saved	Average yield (selections saved)	Crosses with no outstanding selections	Superior selections	Outstanding selections	Average height	Average date of awn emergence
	Grams	*Percent*	*Grams*	*Percent*	*Percent*	*Percent*	*Centimeters*	
1	409.2	18.2	507.0	81.8	5.5	0.8	86.1	June 12.8
2	445.6	23.3	524.2	60.4	11.0	3.0	90.2	June 13.2
3	467.3	33.0	535.1	40.2	12.6	5.1	86.4	June 11.7
4	485.1	39.6	538.8	36.7	19.0	5.3	85.4	June 12.1
5	499.1	50.3	542.8	14.3	29.1	11.8	84.8	June 10.1

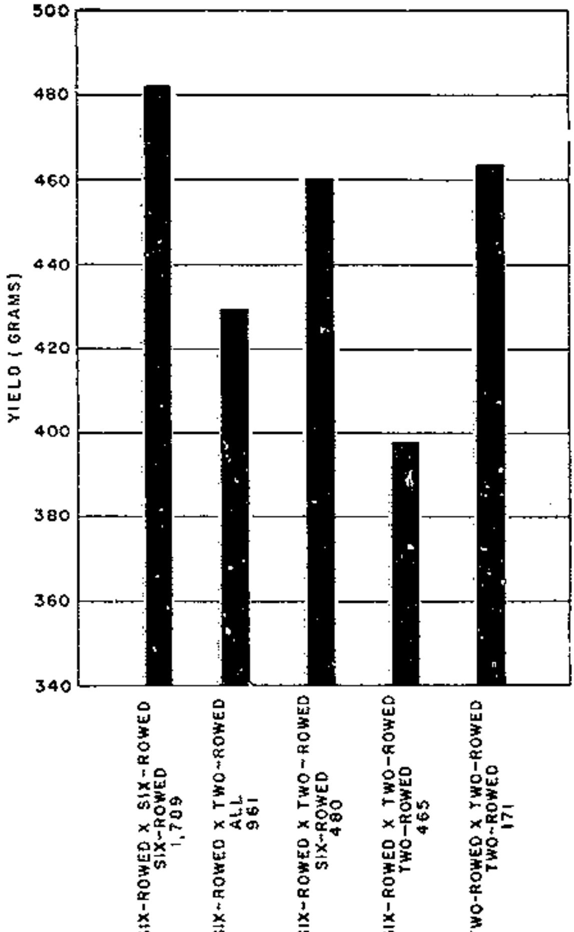

FIGURE 4.—Average yield of 1,789 six-rowed selections from six-rowed × six-rowed crosses, of 171 two-rowed selections from two-rowed × two-rowed crosses, and of 961 selections from six-rowed × two-rowed crosses, the last-named group comprising 480 six-rowed selections, 465 two-rowed selections, and 16 intermediums (not represented as a separate group).

TABLE 6.—*Number of selections, date of awn emergence, height, and average yield in grams of selections originating from crosses of six-rowed × six-rowed, six-rowed × two-rowed, two-rowed × two-rowed, and from a composite mixture of all these combinations*

Origin	Selections	Average date of awn emergence	Average height	Average yield
SAVED AT ABERDEEN				
Pedigree crosses:	*Number*		*Centimeters*	*Grams*
Six-rowed × six-rowed	759	June 10.3	85.6	539.8
Six-rowed × two-rowed	167	June 12.5	85.9	512.5
Two-rowed × two-rowed	39	June 13.5	85.8	515.8
Total	965	June 10.8	85.7	534.1
Composite	1,269	June 11.3	87.6	540.7
Total	2,234	June 11.1	86.8	537.9
DISCARDED OR SENT ELSEWHERE				
Pedigree crosses:				
Six-rowed × six-rowed	1,030	June 11.7	87.1	439.3
Six-rowed × two-rowed	794	June 13.4	87.7	411.4
Two-rowed × two-rowed	132	June 14.3	86.5	446.5
Total	1,956	June 12.6	87.3	428.5
Composite	1,652	June 13.5	88.6	434.0
Total	3,608	June 13.0	87.9	431.0
TOTAL (ALL SELECTIONS)				
Pedigree crosses:				
Six-rowed × six-rowed	1,789	June 11.1	86.5	482.0
Six-rowed × two-rowed	961	June 13.3	87.4	428.9
Two-rowed × two-rowed	171	June 14.1	86.3	462.3
Total	2,921	June 12.0	86.8	463.4
Composite	2,921	June 12.6	88.1	480.4
Grand total	5,842	June 12.3	87.5	471.9

The writers can offer no explanation for the reduced yield. Reduction in yield, however, is only a part of the inferiority of such crosses. The full size of the lateral kernels of the six-rowed parent is seldom recovered in the six-rowed segregates. The lateral kernels are often so small that many of them would not be recovered in a commercial threshing outfit. In less extreme cases, the reduced size of the lateral kernels results in poor quality. The effect of small laterals on total yield is not known. Although the average of all selections was low, there were occasional segregates that produced very large yields. Some strains thus produced superior yields despite the small size of the lateral kernels. Many of these strains had to be discarded because of low quality. Of course, there were a few six-rowed selections from the six-rowed × two-rowed crosses in which the laterals were comparable with those from the six-rowed × six-rowed crosses.

The only evidence that appears favorable to six-rowed × two-rowed crosses is really unfavorable. The highest average yield of selections saved (table 7) came from the six-rowed selections out of these crosses. The average is high, because the quality was usually so poor that only those rows with very high yields were saved. Eighty percent were discarded.

TABLE 7.—*Number and average yield of selections grouped in morphological classes*

Character of selections	Selections		Average yield of—	
	Total	Saved	All selections	Selections saved
	Number	*Number*	*Grams*	*Grams*
Six-rowed from—				
Six-rowed × six-rowed	1,789	759	482.0	539.8
Six-rowed × two-rowed	480	96	459.9	543.0
Composite	2,703	1,237	485.3	541.4
Total	4,972	2,092	481.6	540.9
Two-rowed from—				
Six-rowed × two-rowed	465	70	397.4	471.4
Two-rowed × two-rowed	170	39	463.0	515.8
Composite	210	32	420.7	512.0
Total	845	141	416.4	492.9
Intermedium	25	1	402.9	460.0
White from—				
Six-rowed × six-rowed	798	370	489.9	539.3
Six-rowed × two-rowed	659	128	426.6	510.6
Two-rowed × two-rowed	150	35	462.8	517.6
Composite	1,237	494	473.4	537.6
Total	2,844	1,027	467.1	534.2
Blue from—				
Six-rowed × six-rowed	991	380	475.6	540.4
Six-rowed × two-rowed	302	39	429.7	518.6
Two-rowed × two-rowed	21	4	458.6	498.5
Composite	1,684	775	485.5	542.7
Total	2,998	1,198	476.4	541.0
Rough	4,856	1,898	476.8	510.0
Smooth	888	323	454.0	527.0
Hooded	98	13	389.6	501.2
Covered	5,783	2,220	472.6	538.1
Naked	59	14	405.1	505.8

It is interesting to note that, although the whole experiment was conceived and carried out with no thought of making a contribution to genetics, the behavior of the six-rowed × two-rowed crosses has important genetic significance and is revealed, and perhaps could only be revealed, by a rather unorthodox approach.

METHODS OF SELECTING FROM PEDIGREE POPULATIONS

The only object of the practical breeder in making hybrids is to produce a superior variety. Except in backcrossing, which is not within the field of this bulletin, the problem is to find the best segregates. Each breeder has his favorite method, but they differ mostly in the time selections are made. Some prefer to select in the F_2 generation and to reselect until desirable homozygous strains are found. Others wait until most of the heterozygosity disappears. There is not much actual evidence on the value of the different methods. In this experiment selections were made from the pedigree crosses in the eighth generation. Very few discernibly heterozygous forms were found, and it is thought that many of the weaker strains were already eliminated. However, the only definite evidence that might be used as a guide in breeding from pedigree crosses is the correlation between the yields of the pedigree rows before selection and the yields of the selections made in the F_8 generation.

An analysis of the yield groups in table 5 reveals this relationship. It will be recalled that the 379 crosses were placed in 5 groups according to their yields before selections were made. From the very low-yielding group 5 selections were chosen. From the very high-yielding group 15 were taken, etc. In table 5 it will be seen that this relationship was maintained in the yield of the selections tested later. That is, the plant selections made from the low-yielding group in 1935 were consistently low in yield in 1936, and those made from the high-yielding group were consistently high. Not only was this yield relationship maintained, but there was no discrepancy no matter from what angle they were appraised. The average yields of all selections are in the same order as the yields of the groups of crosses before selecting. The same is true of the selections saved. Such a comparison is, in a way, favorable to the groups in which fewer selections were made in that those saved theoretically represent only the very best strains (18.2 percent in group 1, table 5) while in the groups with a higher number of selections saved not only the best are supposedly present but also poorer ones. This is even more true with the percentage of superior and outstanding selections. Yet every single class remains in the same order. It is obvious that the classification previous to selection was significant and that the season of 1936 was comparable with that of previous years and the test valid. So much coincidence could not be accidental. Moreover, the correlation of the preselection yields of the crosses with the yields of selections made later has been pointed out twice before in this bulletin (pp. 8, 13). This relationship was evident when the yields of both crosses and selections were listed by parents and again when they were classified according to whether they involved six-rowed×six-rowed or six-rowed×two-rowed matings. Thus, when the 2,921 selections of known origin were divided in any of three distinct ways, the preselection yields were shown to be significant, and from the standpoint of the practical breeder it is evident that the low-yielding crosses offer little hope of superior selections and may as well be discarded.

COMPARISON OF SELECTIONS MADE FROM PEDIGREE CROSSES WITH THOSE MADE FROM THE COMPOSITE

The composite was made by mixing equal amounts of seed of the same 379 crosses in the F_2 generation. This mixture was grown in a field plot year after year. Equal numbers of selections were made from this plot and from the pedigree crosses, 2,921 from each. A comparison of the two methods, however, is not simple. An inspection of table 6 would indicate that the composite method was the best. Not only is the average yield of all selections from the composite better, 480.4 gm. as against 463.4 gm., but a larger number was worthy of further testing. From the pedigree crosses 965 were continued, and from the composite 1,269 were saved for test in 1937.

It has already been pointed out that six-rowed×two-rowed crosses are inferior in yield. Granting that the breeder is able to select good plants, there would be a much smaller number of selections from the composite tracing to six-rowed×two-rowed crosses. This is particularly true because the six-rowed selections from such crosses often have poorly developed lateral kernels and would not be chosen. A more detailed analysis is made in table 7. It will be seen in that table that the six-rowed selections from the six-rowed×six-rowed crosses yielded 482.0 gm. as against 485.3 gm. for those from the composite. Here again there are complicating factors. Some of the six-rowed× six-rowed crosses were poor, and too many or too few selections may have been made from them as compared with their rate of elimination in the composite. Yet if they have been eliminated by natural selection, it is hardly an argument against the composite method. It is impossible to compensate for all the factors that may be present and it cannot be predicted as yet from which method the very best selections will be obtained. So far as is now apparent, the composite method is at least equal to that in which the identity of the crosses is maintained. Theoretically the best selections should still be found in both lots, and the results here reported indicate that this is the case.

PLANT CHARACTERS

A number of plant characters were studied with the hope of discovering the most desirable plant type. Perhaps there is an optimum height, a most favorable date of flowering, etc., but a careful analysis of the data leaves some doubt. Superficially, when all the tables are studied, it would appear that the perfect plant at Aberdeen is 90 cm. high; that it flowers between June 5 and 13; and that it is six-rowed, rough-awned, covered, and blue in color. Part of this description seems incontrovertible. For instance, it is apparent in table 7 that the two-rowed strains produced lower average yields than the six-rowed ones, no matter how the comparison is made. The hooded forms also are inferior. The average yield of all selections was 471.9 gm. The 98 hooded strains produced an average of only 389.6 gm., which, as may be seen in table 3, is far below the average of Meloy, the parent from which the hooded characteristic was derived. Obviously hoods or lack of awns are a handicap at Aberdeen. Naked barleys appear slightly less productive than covered ones. The 59 naked sorts produced an average yield of 405.1 gm., whereas all 173 strains from Everest, the naked parent, produced an average of 444.7 gm. (table 2). If the absence of hull is compensated for, the figures would be closer together, but as the 444.7 average includes the naked ones, it would require 15 percent of hull to make them equal in weight. The percentage of hull never reaches this figure on well-developed grain, and the hulls of Everest segregates usually are very thin. The naked sorts are, therefore, inferior in yield in this experiment, and as Everest was crossed on 27 other varieties, the results are presumably of significance.

The value of the smooth-awned barleys is more difficult to determine. It appears in table 7 that the rough-awned sorts were distinctly better on the average. In table 8 the yields of the rough-, smooth-awned, and hooded selections are arranged by date of awn emergence. The reason for this arrangement is more apparent in figure 5. It so happened that there was a frost on June 9. The low temperature seemed to affect the smooth-awned sorts more than it did the rough ones. Smooth-awned sorts emerging before June 9 were essentially equal to the rough-awned ones in yield. The frost is probably only a partial explanation of the difference in yield. The factors associated with smooth awns are only partly understood. The lemmas and palets of smooth-awned barleys, for instance, usually are not so firmly cemented to the caryopsis as is the case in the rough-awned ones. Floret sterility is much more common. Almost without exception the

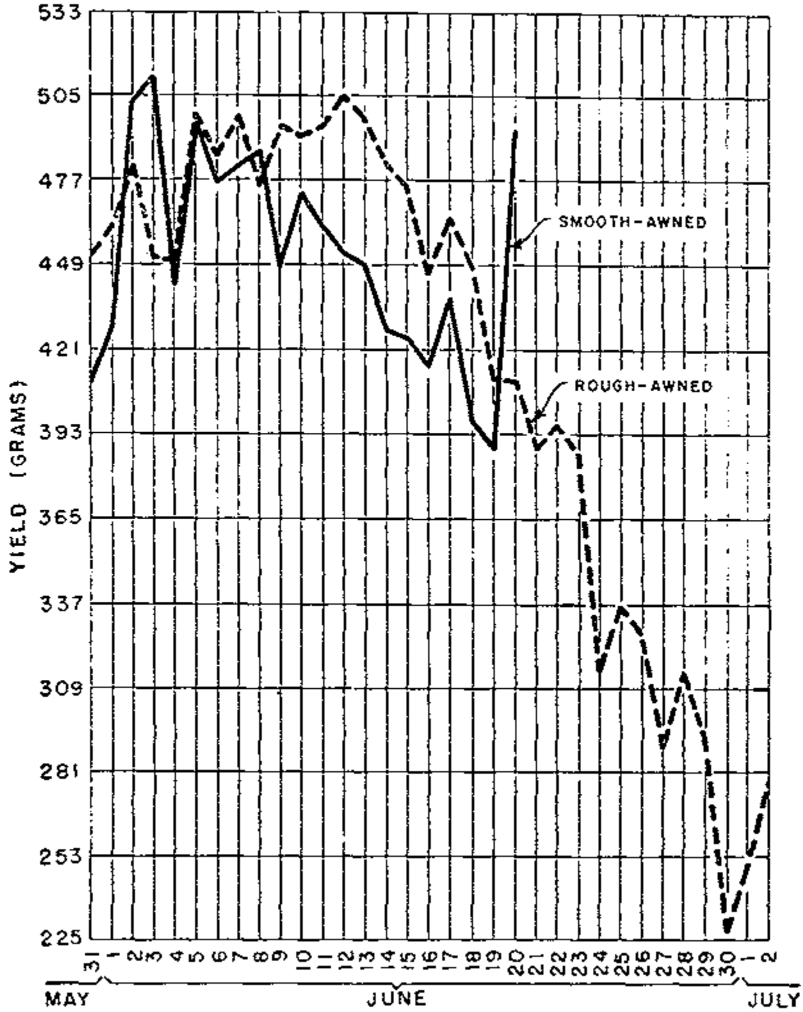

FIGURE 5.—Average yield of rough and smooth selections arranged by date of awn emergence, showing effect of frost of June 9 on smooth-awned selections.

stigma hairs disappear about in proportion to the disappearance of teeth from the awns. This doubtless is a factor in sterility. The writers believe that possibly the best commercial barley might be one with some roughness left at the tip of the awns. The teeth here are small and not objectionable. Slightly rough forms are characterized by a larger number of stigma hairs than is found in the fully smooth forms. It is also thought possible that the high correlation of teeth on awns and stigma hairs sometime may be broken down. However complex the reasons, the average yield of the smooth-awned segregates is somewhat less than that of the rough ones. Occasional smooth strains do produce high yields, and only the probabilities seem certainly less.

Table 8.—*Average yield of rough, smooth, and hooded selections and total of all selections by date of awn emergence*

Date of awn emergence	Selections and yields							
	Rough		Smooth		Hooded		Total	
	Number	Average yield	Number	Average yield	Number	Average yield	Number	Average yield
		Grams		*Grams*		*Grams*		*Grams*
Before June 1	14	452.2	9	410.8			23	436.0
June 1	14	462.1	7	426.0			21	450.8
2	22	481.4	13	503.2			35	489.5
3	37	451.0	9	512.7			46	463.1
4	50	449.9	26	442.1			76	447.3
5	92	498.1	39	496.2			131	497.5
6	273	485.0	86	474.8	5	469.0	364	482.4
7	106	498.6	32	481.2	1	348.0	139	493.5
8	165	475.0	34	486.8	6	398.2	205	474.7
9	284	495.5	48	447.4	13	422.0	345	381.7
10	345	491.8	89	472.9	15	397.3	449	494.9
11	424	494.1	84	461.0	13	399.8	52[illegible]	486.4
12	473	505.7	109	451.8	12	403.1	594	493.7
13	519	497.7	62	448.5	10	385.8	591	490.6
14	526	482.1	82	427.7	5	342.6	613	473.7
15	420	475.0	66	423.8	5	392.8	493	467.1
16	309	444.5	35	415.2	4	331.0	348	440.2
17	294	464.4	35	437.6			329	461.5
18	196	448.6	14	397.7	4	330.5	214	443.1
19	87	411.4	4	388.3	3	341.3	94	408.1
20	58	410.1	3	492.0	1	365.0	62	413.3
21	55	387.0					55	387.0
22	18	395.5					18	395.5
23	11	386.1			1	295.0	12	378.5
24	11	314.3					11	314.3
25	7	336.9					7	336.9
26	7	327.6					7	327.6
27	5	289.8					5	289.8
28	9	313.1					9	313.1
29	7	292.4					7	292.4
30	8	227.1					8	227.1
July 1	8	249.1					8	249.1
After July 1	2	277.5					2	277.5
Total	4,856	476.8	388	454.0	98	389.6	5,842	471.9

The optimum date of awn emergence, which is probably 1 or 2 days earlier than flowering, covers a considerable range of time. It will be seen in table 8 and in figure 5 that high yields were obtained from selections the awns of which emerged between June 5 and 14, inclusive. This period is thought to be significant. It is complicated only by the grouping of the better parents. The average awn-emergence dates of segregates tracing to specific parents are given in table 9. Although the awns of the average selection from most of the better parents emerged between June 9 and 12, the averages of Han River, Trebi, Arequipa, and Algerian are later. In fact, the average of the latest parent, Golden Pheasant, came before June 16.

TABLE 9.—*Varieties listed in order of date of awn emergence and again in order of height, with the rank of the average yield of all selections from the 27 crosses in which such variety was one parent*

Variety	Average date of awn emergence	Rank of average yield	Variety	Average height	Rank of average yield
	June			*Centimeters*	
Flynn	8.9	5	Palmella Blue	76.5	16
California Mariout	9.7	10	California Mariout	77.7	10
Club Mariout	9.7	3	Good Delta	79.3	9
Minia	9.7	4	White Smyrna	80.3	23
Palmella Blue	9.9	16	Minia	82.8	4
Atlas	10.0	1	Lion	83.0	15
Good Delta	10.4	9	Flynn	83.9	5
Maison Carré	10.7	7	Everest	84.8	21
White Smyrna	11.0	23	Meloy	84.8	18
Lion	11.2	15	Maison Carré	84.9	7
Multan	11.2	19	Lyallpur	85.7	14
Meloy	11.3	18	Han River	86.3	13
Han River	12.0	13	Multan	86.4	19
Trebi	12.0	6	Trebi	86.6	6
Lyallpur	12.1	14	Atlas	86.6	1
Sandrel	12.4	8	Sandrel	86.6	8
Everest	12.6	21	Algerian	86.9	11
Wisconsin Winter	12.9	17	Club Mariout	87.0	3
Glabron	13.0	28	Wisconsin Winter	87.9	17
Manchuria	13.1	20	Hannchen	88.6	22
Arequipa	13.1	2	Golden Pheasant	89.3	27
Algerian	13.7	11	Horn	90.4	25
Horn	13.9	25	Orel	90.6	12
Alpha	14.3	24	Alpha	92.2	24
Oderbrucker	14.5	26	Arequipa	92.5	2
Hannchen	14.5	22	Glabron	94.6	28
Orel	14.5	12	Manchuria	96.0	20
Golden Pheasant	15.8	27	Oderbrucker	99.5	26

It is difficult to discover what it is that any one parent contributes. Occasionally there is a factor that seems significant. For instance, the variety California Mariout is very early at Aberdeen, but it does not yield well there. Since it is among the better parents and since very late selections (table 8) did not produce high yields, it is possible that earliness was the yield factor contributed by this variety that placed it among the better ones.

The relation of height to yield is much more complicated. The heights reported represent the length of culm as measured from the base of the spike to the ground. When the selections are arranged in height groups (table 10), there is an obvious peak of yield at 90 cm. This peak is difficult to interpret. The problem is complicated both by soil variations and the distribution of good parents. No field is entirely uniform, and the better spots produce the highest yields and at the same time the tallest plants. Since the average height of the progenies of 9 of the best 10 parents falls on 85 cm., it is thought that the 90-cm. peak is probably about 5 cm. too high. Because the same inference can be drawn from independent data in table 5, where the average height of the selections in the best two yield groups is found to be 85.1 cm., it would seem that the highest yields, if soil variations were accounted for, would be from selections averaging about 85 cm. in this year. Of those with progeny height averages greater than 90 cm., only Arequipa is found among the best 10 (table 9). The lower trend of yield of those selections taller than 90 cm. may be due, at least in part, to the parents involved. Even with a soil correction, it would seem that the best selections were slightly taller than average as compared with the mode of the population of the crosses from which they came. Possibly the same vigor that resulted in high yields added something to the plant stature.

TABLE 10.—*Number and average yield of 5,842 selections arranged by height*

Height (centimeters)	Selections	Average yield	Height (centimeters)	Selections	Average yield
	Number	*Grams*		*Number*	*Grams*
45	1	418.0	85	1,011	483.5
50	3	406.0	90	944	491.1
55	12	404.6	95	748	470.2
60	37	376.6	100	525	464.5
65	103	423.8	105	341	465.1
70	327	430.2	110	178	465.9
75	561	404.2	115	52	484.2
80	987	475.5	120	12	457.3

The value of color is not established. Most barleys from regions of bright sunlight are characterized by blue pigment in the aleurone. It is possible that it has a mild protective function. The average yield of 2,998 blue strains (table 7) was 476.4 gm.; the average of 2,844 white strains was 467.1 gm. Considering the numbers involved, this would be significant if they were strictly comparable, but they are not. As has been shown earlier, the six-rowed × two-rowed crosses were inferior. Six of the seven two-rowed barleys were white. When the figures are broken down, the white barleys from the six-rowed × six-rowed crosses are seen to be better than the blue ones from these crosses. On the other hand, the blue from the composite were better than the white from this same source. If blue pigment has any function, it is too slight to be of much hindrance to the plant breeder.

VALIDITY OF THE TEST

The experiment reported was on an extensive scale, and all analyses made by the writers indicate an unusual agreement so far as the major features were concerned. As mentioned earlier, all characters, varietal progenies, and strains obtained by different methods of handling were in large number and distributed in a highly random manner. The agreement between the rank of yields of the pedigree rows and the rank of yields of selections made therefrom was striking. The crosses were carried as unselected populations for 7 generations before selections were made. Yields on each cross before selections were made were at hand as well as the yields of the selections made in the F_8 and tested in the F_9 generation. Each variety was crossed on 27 others. When the average yields of the unselected populations of the 379 crosses are grouped by parents, an index of the usefulness of the varieties is obtained. This is expressed in table 3 by the number of selections made. The 12 parents, from which more than 210 selections were made, included 11 of the 12 with the highest average yield of selections. They also are responsible for the greatest number of superior and outstanding selections.

When the 379 crosses are grouped according to their preselection yields into yield groups independent of parentage (table 5), the grouping is again in absolute agreement with the yields of the selections made later. The better groups account for an even higher percentage of the superior and outstanding selections.

If the preselection yields of the six-rowed × two-rowed crosses are compared with the selections made from them, it will be found that they are in the same relative position to the six-rowed × six-rowed and two-rowed × two-rowed (figs. 4 and 5). The six-rowed × two-rowed crosses are definitely inferior in each case.

One source of possible error was not covered in the analyses. The 308 Trebi checks produced an average yield of 550.8 gm. as compared with 471.9 gm. for the 5,842 selections. Trebi has long been the leading variety at Aberdeen, and it was thought possible that the high yields of this variety might adversely affect the adjacent rows. It will be seen in table 11 that this was not the case. In fact, the adjacent rows were better than those not adjacent. This table naturally raises the question, unrelated to validity, as to how many strains may eventually prove to be better than Trebi. Obviously this cannot be answered as yet, but it now appears that there will be a considerable number.

TABLE 11.—*Effect of a high-producing check on adjacent rows*

Class	Rows	Average yield
	Number	*Grams*
Trebi check	308	550.8
Adjacent rows	616	474.3
Rows not adjacent	5,226	471.6

PLANS FOR FURTHER WORK

It is realized that more questions have been raised than answered in this experiment. Evidence on two or three important questions has been obtained, but there remain numerous others that are worth investigating despite the fact that all such studies require an immense amount of work and much time. Plans are under way to continue the study of methods. At the same time a more elaborate breeding program based on improvements suggested in this effort is being evolved. The new plan may result in a breeding scheme of much greater value. One of the weaknesses of the scheme presented was the absence of compound matings. All possible combinations were made, but no combination brought together more than two parents. The project now being developed utilizes compound matings as its basic conception. A systematic series of bridging crosses is being attempted. Single crosses have already been made as follows: $a\times b$, $c\times d$, $e\times f$, $g\times h$. In a second mating these F_1 plants will be crossed to obtain the double crosses $(a\times b)\times(c\times d)$ and $(e\times f)\times(g\times h)$. In a third mating the double crosses would be combined as follows: $[(a\times b)\times(c\times d)]\times[(e\times f)\times(g\times h)]$. As segregation will already have started at the time of the second crossing, a greater number of crosses would need to be made than in the first mating, while in the third mating a very large number of seeds would be desired. In the third mating every seed is essentially a new cross and will presumably result in a different combination of characters. The possibilities of unusually favorable matings and hence, of exceptional segregates, are increased by the increased number of hybrid combinations. For obvious reasons no two-rowed varieties have been included. Three projects are now in progress in which different parents are used for the making of crosses suitable for different sections of the country. It is thought that for this type of breeding the plan now being attempted has great possibilities.

SUMMARY AND CONCLUSIONS

A total of 379 barley crosses were grown for 7 generations in separate rows in which their identities were maintained.

Equal amounts of seed of the same 379 crosses were mixed in the F_2 generation and grown in a field plot as a composite lot through the seventh generation in 1934.

In 1935, 1 acre was space-planted, half of the area being seeded to pedigree crosses and half to the 1934 composite.

An equal number of selections (2,921) was made from each lot.

In 1936 the selections were grown in effectively random order and compared in yield.

For Aberdeen conditions, the best parents came from north Africa and Armenia. Fair varieties were found from the Balkans, southern Soviet Union, India, and China. Barleys from northern Europe and Manchuria were not promising.

The best parents were Atlas, Minia, Trebi, Club Mariout, Arequipa, Sandrel, Flynn, Maison Carré, Algerian, Good Delta, California Mariout, and Han River.

Varieties grown commercially in the United States usually were found to have too many characters specifically suited to their localities to be highly useful as parents in a distinctly different area.

Some varieties that were not quite equal to the best ones in plot tests proved to be highly desirable parents.

Two varieties, Minia and Good Delta, that had not been sufficiently promising in nursery tests to be grown in plots, were found to be superior parents. As the Division collection is made up of such barleys, it probably contains many varieties that as parents are the equal of the best-known sorts.

Hybrids resulting from crosses of six-rowed × two-rowed barleys were inferior in yield during the seven generations they were carried in bulk, and were likewise responsible for very few high-yielding segregates among the selections made in the eighth generation.

The yields of the pedigree crosses before selections were made were a sound indication of the crosses from which high-yielding segregates might be expected, and the low-yielding crosses could have been discarded on the basis of their preselection yields without loss.

Growing a number of crosses in a composite mixture was apparently equal to the method of pedigree cultures.

Six-rowed segregates were better than two-rowed ones.

Hooded segregates were definitely inferior to awned ones.

Naked segregates were slightly less productive than covered ones.

Midseason barleys were best adapted to Aberdeen conditions.

Smooth-awned forms averaged greater floret sterility and slightly lower yields. Some individual smooth strains may prove to be the equal of the best rough ones.

Segregates of average or slightly more than average height probably were better than very tall ones.

Blue color in the aleurone probably was not related to capacity to yield.

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