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TEXAS AGRICULTURAL EXPERIMENT STATION

B. YOUNGBLOOD, DIRECTOR
COLLEGE STATION, BRAZOS COUNTY, TEXAS

BULLETIN NO. 359 MAY, 1927

DIVISION OF AGRONOMY

HYBRID VIGOR IN SORGHUM

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†As of May 1, 1927.
*On Leave.
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****In cooperation with the School of Agriculture.

SYNOPSIS

This Bulletin discusses the results attending the crossing of different strains of sorghum of the same variety with one another and of different varieties with one another. Studies of this character are of particular interest to plant breeders in connection with the development of new and superior strains and also to the grower in the practice of growing planting seed.

The data presented show that crosses between different varieties of sorghum exhibit marked hybrid vigor as measured by the height of plant. These crosses also exhibit unusual hybrid vigor in the size of leaves, chlorophyll development, and production of grain, and are characterized by a marked delay in the time of maturity. On the other hand, crosses between strains of the same variety either do not exhibit vigor at all or display it only in the height of the plant.

The practical application of the data presented lies in the fact that hybrid vigor may be carried over into succeeding generations and may, therefore, be of practical importance to plant breeders in securing improved strains by obtaining recombinations which retain desirable growth factors. It will also be of value in the study of the relationship of the different varieties of sorghum. It further affords a basis for the farmer to arrange his seed fields in such a way that in the succeeding crop rogueing can be practiced with the certainty of eliminating first-year hybrids.

CONTENTS

BULLETIN No. 359 MAY, 1927

HYBRID VIGOR IN SORGHUM

A. B. CONNER AND R. E. KARPER
Texas Agricultural Experiment Station

The study of hybrid vigor or heterosis is a matter of common interest to the student of heredity and to the breeder. Maize furnishes a most interesting example of hybrid vigor, and the knowledge obtained affords a basis for the practical utilization of it by breeders in the production of seed corn. In grain sorghum, no such practical advantage seems possible on account of the fact that it is difficult to obtain first-year hybrid seed in quantity sufficient for field use. In studying hybrid vigor in sorghums, therefore, the plant breeder is mainly interested in (1) the increased vigor which can be retained in later generations by the recombination of favorable growth factors, (2) the relationship of different varieties as indicated by the degree of heterosis which follows their crossing, and (3) establishing a basis for eliminating natural hybrids from fields of pure-bred varieties grown for seed.

A study of hybrid vigor in different crosses opens up to the breeder a better working knowledge of the complexity of the hereditary mechanism with which he is working. In maize, a crop which is largely cross-fertilized, one finds that within a variety the various families represented have crossed and inter-crossed to such extent that the genetic constitution is very complex. On the other hand, in sorghum, a crop which is largely close-fertilized, one finds that within a variety a number of families or strains are represented in practically pure form, each retaining its identity without contributing a great deal to the complexity of neighboring families by cross-pollination. The smallness of the amount of natural cross-fertilization is perhaps responsible in a large measure for the ease with which new strains can be isolated by selection, and, on the other hand, it probably plays no small part in contributing toward making it relatively easy to recover from hybridized families strains that are homozygous in a sufficient number of characters to be acceptable to the layman as a distinct variety. A knowledge of hybrid vigor, therefore, in sorghum should contribute toward a better understanding of the genetic complex of the sorghum plant and promote the use of more effective breeding methods.

It is the purpose of this Bulletin to present data obtained at the Lubbock Substation from crossing different varieties of grain sorghum with one another, and, as well, data obtained from crossing sub-varieties or strains of grain sorghum with one another. The data presented here relate exclusively to height measurements, and since height is known to be one of the reliable measures of hybrid vigor, these height measurements furnish a means of estimating hybrid vigor in crosses.

Materials

The materials used in this study include the three strains of milo known as Extra Dwarf, Dwarf, and Standard; and three strains of feterita known as Extra Dwarf, Dwarf, and Standard. It is noteworthy that in both milo and feterita parallel forms have been developed in so far as stature is concerned. The mean height for Extra Dwarf milos and feteritas ranged from 56 to 72 centimeters. The Dwarf forms of milo and feterita used ranged from 94 to 110 centimeters in height, and the Standard forms of milo and feterita used ranged from 125 to 147 centimeters in height. The Extra Dwarf, as well as the Dwarf form of feterita, has been developed by the Texas Station. All of the materials used were uniformly true to type in so far as height is concerned, as is shown by the parental heights in the tables. None of the varieties used, however, were directly from bagged seed. In other words, the parental material as used in this work was from open fertilized seed representative of the varieties as kept pure by the ordinary methods.

Methods

When the crosses used in this study were made, the practice was followed of bagging the two parent heads together in the same bag and shaking the bag occasionally from time to time to more thoroughly distribute the pollen. This resulted in cross-fertilization of a small percentage of the seeds in the bagged heads. All of the seed of the bagged heads were planted in the field and the hybrid plants were identified by the increased vigor which they displayed, or the increased height over the selfed seed. The dwarf strain was used as the mother parent, as previous experiments had shown that F_1 plants could be recovered with certainty by reason of heretosis or by the display of simple dominance of the tall parent. These first-generation hybrid plants were subsequently planted in head-rows for further verification and measurement.

During the season of 1922, the first-year hybrid plants were measured and their heights were compared directly with the mean heights of the parent varieties grown the same year. In 1923, the second generation rows were compared directly to the height measurements obtained from the parent varieties grown in that year, so that a reasonably accurate measure of both the first and second generation material was obtained as compared to the height of the parent varieties grown in the same season.

Height of Parent Varieties

A description of the parent varieties, in so far as height is concerned, is of basic value in the analysis of data to be subsequently presented.

Moreover, it is desirable to have a measure of parent varieties grown under the seasonal conditions obtaining in both 1922 and 1923, the two years during which the first- and second-generations were given. Accordingly, the means, standard deviation, and coefficient of variation are presented for height of plant of the varieties used. No measurements on the Extra Dwarf varieties were obtained in 1922; however, their measurement for a two-year period is not so necessary, inasmuch as we are concerned primarily with the taller parent.

Table 1.—Height Measurements in Cm. of Parent Material in Seasons of 1922 and 1923.

T. S. No.	Name of Variety	No. of Measurements	Mean	Standard Deviation	Coefficient of Variability
	(1922)				
6312	Extra dwarf feterita..........	....	65*	....	....
4222	Extra dwarf yellow milo.......	....	72*	....	....
5985	Dwarf feterita...............	40	110.00 ±1.09	10.23 ± .77	9.30 ± .70
670	Dwarf yellow milo............	40	104.25 ±1.64	15.36 ±1.16	14.73 ±1.13
1652	Standard feterita............	40	147.75 ±1.38	12.94 ± .98	8.76 ± .66
3301	Standard milo................	30	144.17 ±2.67	21.72 ±1.89	15.06 ±1.34
	(1923)				
6312	Extra dwarf feterita..........	117	56.95 ± .23	3.76 ± .17	6.60 ± .29
4222	Extra dwarf yellow milo.......	105	65.69 ± .55	8.05 ± .39	12.25 ± .56
5985	Dwarf feterita...............	104	96.46 ± .51	7.66 ± .36	7.94 ± .37
670	Dwarf yellow milo............	84	94.79 ± .57	7.68 ± .40	8.10 ± .42
1652	Standard feterita............	17	125.50 ±2.02	12.37 ±1.43	9.85 ±1.14
3301	Standard yellow milo.........	21	126.93 ±1.99	13.55 ±1.41	10.68 ±1.12

*Interpolated.

All the varieties, under seasonal conditions in 1922, were taller than they were in 1923. (Fig. 1.) This fact is one to be considered later in connection with the heights of the first-generation crosses.

Crosses Between Different Varieties

Three crosses were made between different varieties as follows:

I. Extra Dwarf feterita and Extra Dwarf Yellow milo.
II. Extra Dwarf Yellow milo and Dwarf feterita.
III. Extra Dwarf feterita and Dwarf Yellow milo.

Cross I is between two Extra Dwarf forms of different varieties, the mean heights of the two varieties differing by only 9 centimeters. The table following shows the frequency distribution and statistical constants for the two parents, the first generation, and the second generation.

The mean height of the first-generation plants in 1922 is much greater than the height of the two parents as measured in 1923. The feterita x milo cross shows an increase in height of 130 per cent over

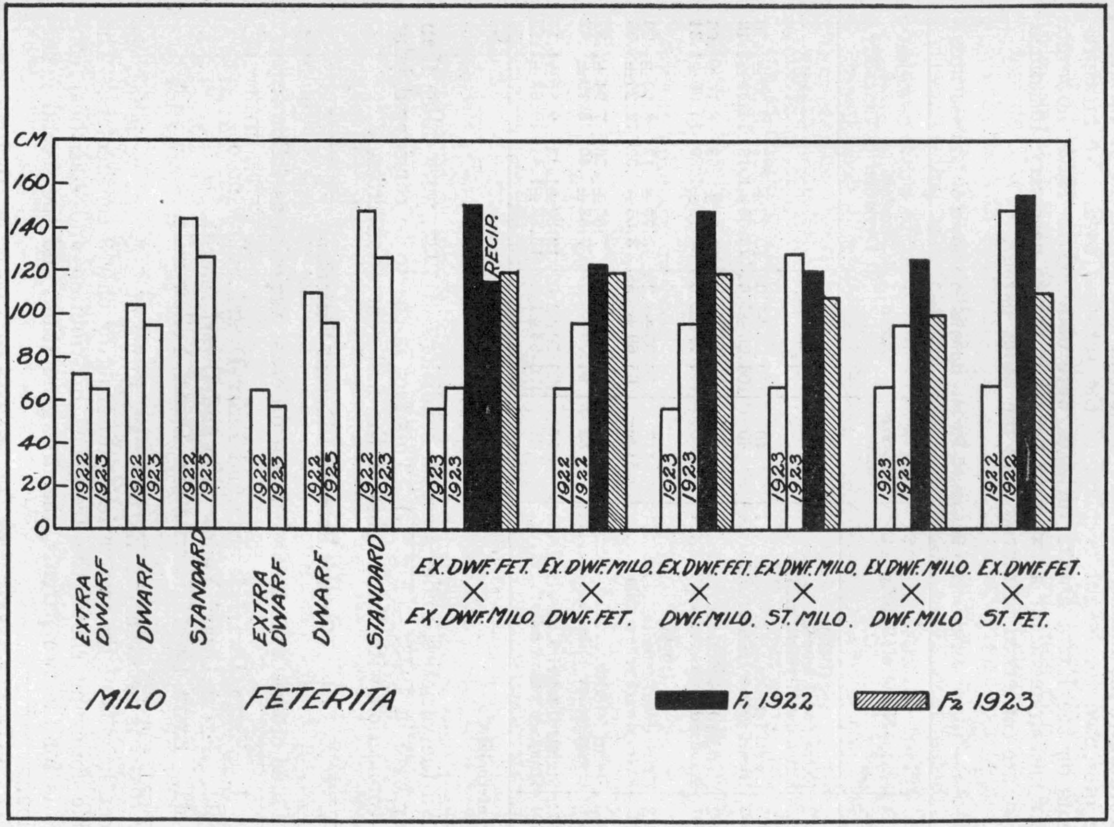


Fig. 1.—Showing the mean height of plant for parental material in 1922 and 1923 and comparison of parents with the F_1 and F_2 hybrids.

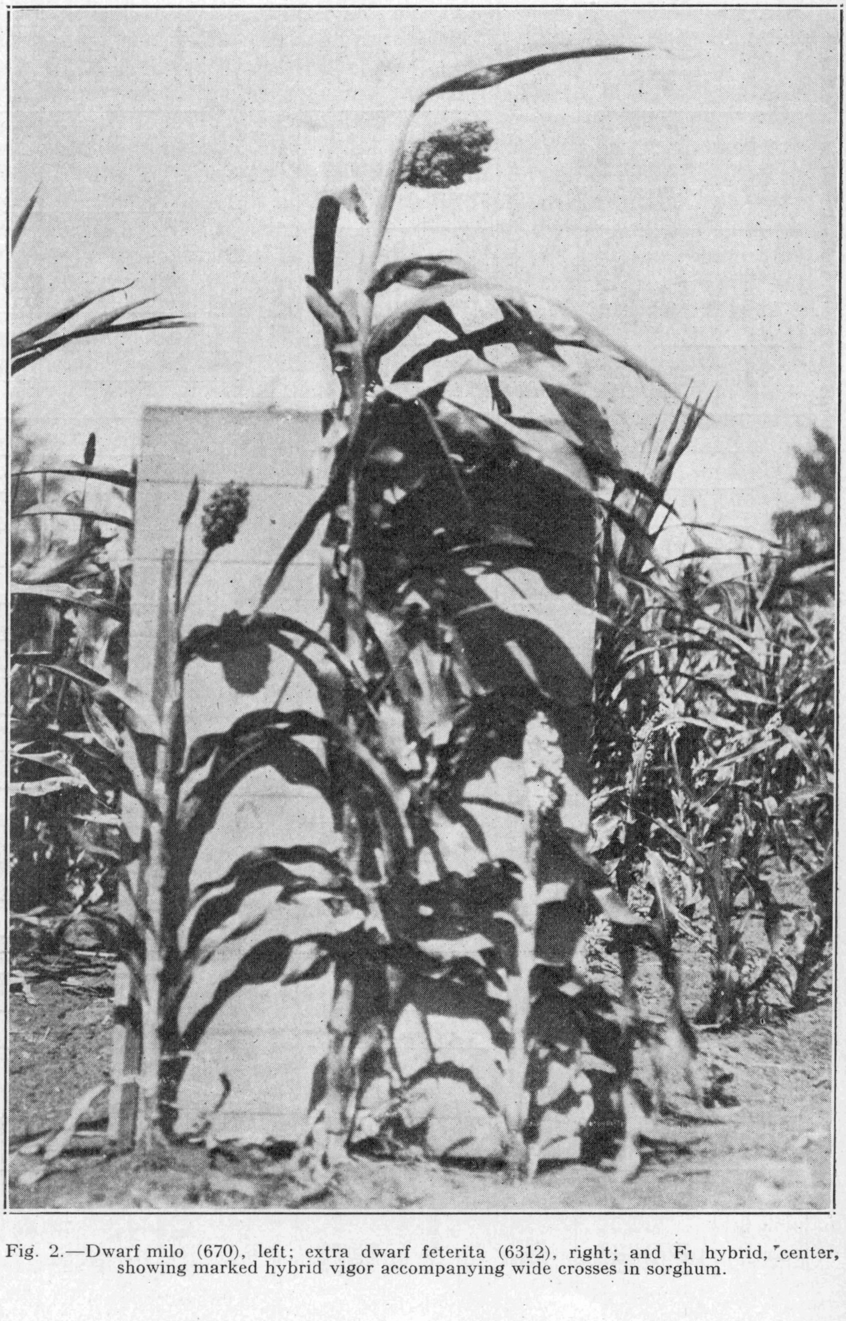


Fig. 2.—Dwarf milo (670), left; extra dwarf feterita (6312), right; and F_1 hybrid, center, showing marked hybrid vigor accompanying wide crosses in sorghum.

CROSS I.

Table 2.—Frequency Distribution of Height of Plant in Cross Between Extra Dwarf Feterita (6312) and Extra Dwarf Milo (4222).

T. S. No. Designation	Year	Generation	Class Centers in Centimeters for Height of Plant 45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205	Total No.	Mean	Standard Deviation	Coefficient of Variability
6312	1923	P	1	98	18	....	....	....	....	....	....	....	....	....	....	....	....	....	....	117	56.95± .23	3.76± .17	6.60± .29
4222	1923	P	1	27	49	25	3	....	....	....	....	....	....	....	....	....	....	....	....	105	65.69± .55	8.05± .39	12.25± .56
6312 x 4222	1922	F_1	....	....	....	....	....	....	....	....	....	1	1	5	....	....	....	....	....	7	151.21±1.86	7.28±1.31	4.82± .87
4222 x 6312	1922	F_1	....	....	....	....	....	1	....	....	2	....	....	....	....	....	....	....	....	3	115.50±5.51	14.14±3.89	12.24±3.42
6312 x 4222	1923	F_2	3	24	43	52	81	63	106	81	70	65	57	51	27	23	7	8	2	763	113.77± .79	32.52± .59	28.58± .53
4222 x 6312	1923	F_2	....	5	9	13	13	18	23	15	17	14	14	15	20	10	3	....	1	190	120.84±1.60	32.64± .89	27.01±1.00

CROSS II.

Table 3.—Frequency Distribution of Height of Plant in Cross Between Extra Dwarf Milo (4222) and Dwarf Feterita (5985).

T. S. No. Designation	Year	Generation	Class Centers in Centimeters for Height of Plant 45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205	Total No	Mean	Standard Deviation	Coefficient of Variability
4222	1923	P	1	27	49	25	3	....	....	....	....	....	....	....	....	....	....	....	....	105	65.69± .55	8.05± .39	12.25± .56
5985	1923	P	....	....	....	1	23	45	35	....	....	....	....	....	....	....	....	....	....	104	96.46± .51	7.66± .36	7.94± .37
4222 x 5985	1922	F_1	....	....	....	....	....	....	....	1	3	....	....	....	....	....	....	....	....	4	123.00±1.46	4.33±1.03	3.52± .84
4222 x 5985	1923	F_2	....	7	18	33	41	50	62	46	68	58	53	30	28	10	4	2	3	513	119.11± .90	30.20± .64	25.35± .57

CROSS III.

Table 4.—Frequency Distribution of Height of Plant in Cross Between Extra Dwarf Feterita (6312) and Dwarf Milo (670).

T. S. No Designation	Year	Generation	Class centers in Centimeters for Height of Plant 45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205	215	Total No.	Mean	Standard Deviation	Coefficient of Variability
6312	1922	P	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	......	65		
670	1922	P	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	40	104.25±1.64	15.36±1.16	14.73±1.13
6312	1923	P	1	98	18	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	117	56.95± .23	3.76± .17	6.60± .29
670	1923	P	....	....	....	3	19	43	19	....	....	....	....	....	....	....	....	....	....	....	84	94.79± .57	7.68± .40	8.10± .42
6312 x 670	1922	F_1	....	....	....	....	....	....	....	....	1	3	1	1	1	1	....	....	....	....	8	146.75±3.85	16.15±2.72	11.01±1.88
6312 x 670	1923	F_2	2	2	10	22	22	24	25	19	33	12	13	18	9	12	3	6	1	1	234	118.49±1.56	35.36±1.10	29.84±1.01

Extra Dwarf milo, the taller parent. The reciprocal cross shows an increase of 74 per cent over the taller parent. The difference in height between the reciprocal crosses is greater than three times the probable error, but the sample is so small, seven plants in one case and five in the other, that little significance can be attached to this observation.

It will be noted that the above comparisons are based on measurements of the F_1 plants in 1922 and parental types in 1923. Unfortunately no measurements of the parental types are available for 1922. Assuming that this relation between the extra dwarf and the standard types was approximately the same in 1922 as in 1923, we can interpolate the height of Extra Dwarf feterita for that year at 64.95 cm. and the height of Extra Dwarf milo at 72.25 cm. A comparison of the calculated height of these two parental types in 1922 with the F_1 hybrids the same year indicates that the hybrids were approximately double (Fig. 2) the height of the taller parent.

The second-generation progeny shows a mean height of 114, as compared with 65 centimeters for the taller parent, the measurements being directly comparable. A considerable amount of hybrid vigor has been carried over into the second generation and shows an increase practically equivalent to that shown in the first generation. As would be expected in the second generation, the variability is strikingly large.

Cross II is between Extra Dwarf Yellow milo and Dwarf feterita, two varieties that differ in height by about 30 centimeters. Table 2 shows the frequency distributions for the two parents, as well as for the first and second generation.

In comparing the mean heights of the parents with the mean height of the first-generation progeny, one sees that a marked increase in height takes place in the first generation of this cross. A direct comparison for height of the first generation with the taller parent shows a difference of 27 centimeters in height in favor of the first-generation progeny, or an increase of 27 per cent. The distribution indicates that, while marked hybrid vigor accompanies this cross, the expression is not so pronounced as in cross I, when the two Extra Dwarf varieties were combined. Vigor extending over into the second generation seems to be fully as prominent as it was in the first generation.

Cross III is another inter-varietal combination between Extra Dwarf feterita and Dwarf Yellow milo, varieties that differ in stature by 38 centimeters. The results of this cross, as judged by the heights, are shown in Table 4.

These two different varieties, when crossed, show a first generation with a mean height of 146 centimeters; that is, they are approximately one-half taller than the parents. An increase of 41 per cent over the tall parent is shown in the first generation and an increase of 25 per cent in the second generation. While this cross is attended by marked hybrid vigor, it seems to be carried over into the second generation in a lessened degree.

If the dwarf and extra dwarf forms in both varieties differ from each other by only a few factors for height and are identical in the remainder of their genetic factors, it might be expected that the F_1 hybrids which result from crossing sub-varieties of milo with those of feterita would attain approximately the same degree of vigor, regardless of the sub-varieties used as parents. In other words, it would seem reasonable to suppose that the F_1 hybrid betwen the two extra dwarf forms would be identical to the hybrid between a dwarf x extra dwarf, a dwarf x standard or even standard x standard. Though the data show that there is some fluctuation in the height of the F_1 plants from the three inter-varietal crosses, the variation is no greater than might well be attributed to the effects of environment and the small size of the sample.

In the F_2 generation, where larger populations were available, the average height is practically the same for every cross, being 113.77 and 120.84 for cross I and 119.11 and 118.49 for crosses II and III, respectively. The coefficients of variability are likewise very nearly the same, 28.58 and 27.01 for cross No. I and 25.35 and 29.84 for crosses II and III, respectively. These facts would seem to indicate that the three crosses represent approximately the same combinations of genetic factors, and that the height differences between sub-varieties of the same variety are not effective when inter-varietal crosses are made.

Although detailed measurements are not available, it may be mentioned that the hybrid plants resulting from these three crosses exhibited heterosis in many characteristics other than height. The stalks were larger and more leafy; the color a deeper green; the heads and plants were heavier, and, unlike hybrid corn plants, considerably later in maturity than either parent.

Crosses Between Strains of the Same Variety

Three crosses were made between strains within the same variety. These were as follows:

IV. Extra Dwarf Yellow milo and Standard Yellow milo.
V. Extra Dwarf Yellow milo and Dwarf Yellow milo.
VI. Extra Dwarf feterita and Standard feterita.

These different strains within varieties have been selected because of inherent differences in height and are distinct in respect to this characteristic. (See Fig. 3.) With the exception of height of plant, the strains within each variety are a counterpart of each other, being identical in other respects. Their genetic constitution is undoubtedly very similar with the exception of the factors for height.

Cross IV is a cross of the Extra Dwarf Yellow milo and the Standard, or tall Yellow milo. These two strains differ in height by 61 centimeters; or, in other words, one is approximately twice as tall as the other, and they afford good material for the study of hybrid vigor. Table 5 shows the frequency distribution and means of the parents,

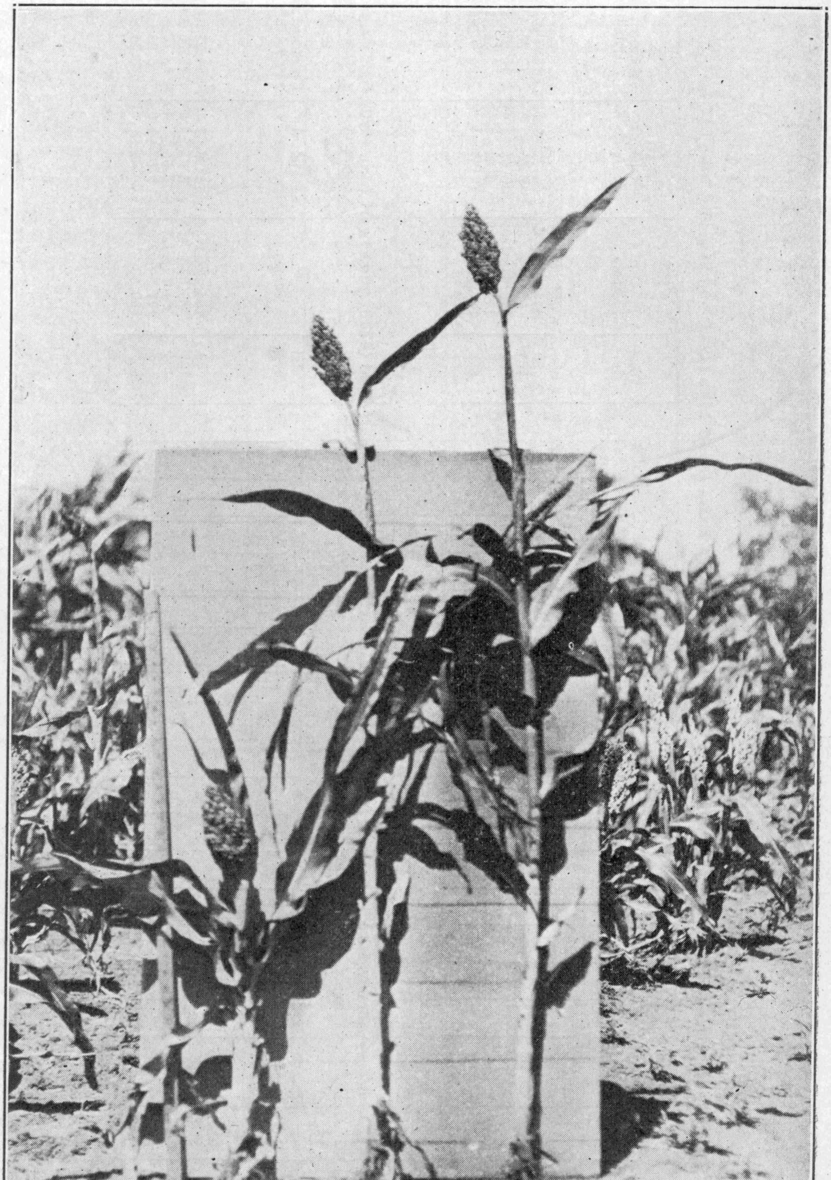


Fig. 3.—Extra dwarf milo (4222), left; standard milo (3301), right; with F_1 hybrid in center. No hybrid vigor accompanies this cross. Height difference between F_1 and tall parent shown here is due to sampling and not significant.

CROSS IV.

Table 5.—Frequency Distribution of Height of Plant in Cross Between Extra Dwarf Milo (4222) and Standard Milo (3301).

T. S. No. Designation	Year	Generation	Class Centers in Centimeters for Height of Plant																	Total No.	Mean	Standard Deviation	Coefficient of Variability
			45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205				
4222	1922	P																		...	75*	...	...
3301	1922	P																		30	144.17±2.67	21.72±1.89	15.06±1.34
4222	1923	P	1	27	49	25	3													105	65.69± .55	8.05± .39	12.25± .56
3301	1923	P						1		6	7	3	3	1						21	126.93±1.99	13.55±1.41	10.68±1.12
4222 x 3301	1922	F_1							2		5									7	119.79±2.30	9.04±1.63	7.54±1.36
4222 x 3301	1923	F_2	2	11	25	38	70	64	115	93	104	64	17	5						608	107.16± .60	21.83± .42	20.37± .41

*Interpolated.

CROSS V.

Table 6.—Frequency Distribution of Height of Plant in Cross Between Extra Dwarf Milo (4222) and Dwarf Milo (670).

T. S. No. Designation	Year	Generation	Class Centers in Centimeters for Height of Plant																	Total No	Mean	Standard Deviation	Coefficient of Variability
			45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205				
4222	1922	P																		...	72*	...	...
670	1922	P																		40	104.25±1.64	15.36±1.16	14.73±1.13
4222	1923	P	1	27	49	25	3													105	65.69± .55	8.05± .39	12.25± .56
670	1923	P				3	19	43	19											84	94.79± .57	7.68± .40	8.10± .42
4222 x 670	1922	F_1								1	2	1								4	125.50±2.38	7.07±1.69	5.63±1.34
4222 x 670	1923	F_2		9	22	31	42	88	64	41	39	24	6							366	100.50± .72	20.44± .51	20.34± .53

*Interpolated.

CROSS VI.

Table 7.—Frequency Distribution of Height of Plant in Cross Between Extra Dwarf Feterita (6312) and Standard Feterita (1652).

T. S. No. Designation	Year	Generation	Class Centers in Centimeters for Height of Plant																	Total No.	Mean	Standard Deviation	Coefficient of Variability
			45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205				
6312........	1922	P	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	67*	....	....
1652........	1922	P	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	40	147.75±1.38	12.94± .98	8.76± .66
6312........	1923	P	1	98	18	....	....	....	....	....	....	....	....	....	....	....	....	....	....	117	56.95± .23	3.76± .17	6.60± .29
1652........	1923	P	....	....	....	....	....	....	1	6	5	3	1	1	....	....	....	....	....	17	125.50±2.02	12.37±1.43	9.85±1.14
6312 x 1652	1922	F_1	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	1	155.50	....	....
6312 x 1652	1923	F_2	....	12	23	7	1	2	7	16	34	21	15	1	....	....	....	....	1	140	108.64±1.81	31.74±1.28	29.21±1.27

*Interpolated.

and of the first and second generations, for height. No heterosis was exhibited in either the first or second generation of this cross. The F_1 generation, based on a small sample, is partially intermediate between the two parent heights in the same year, being 24 cm. shorter than the tall parent.

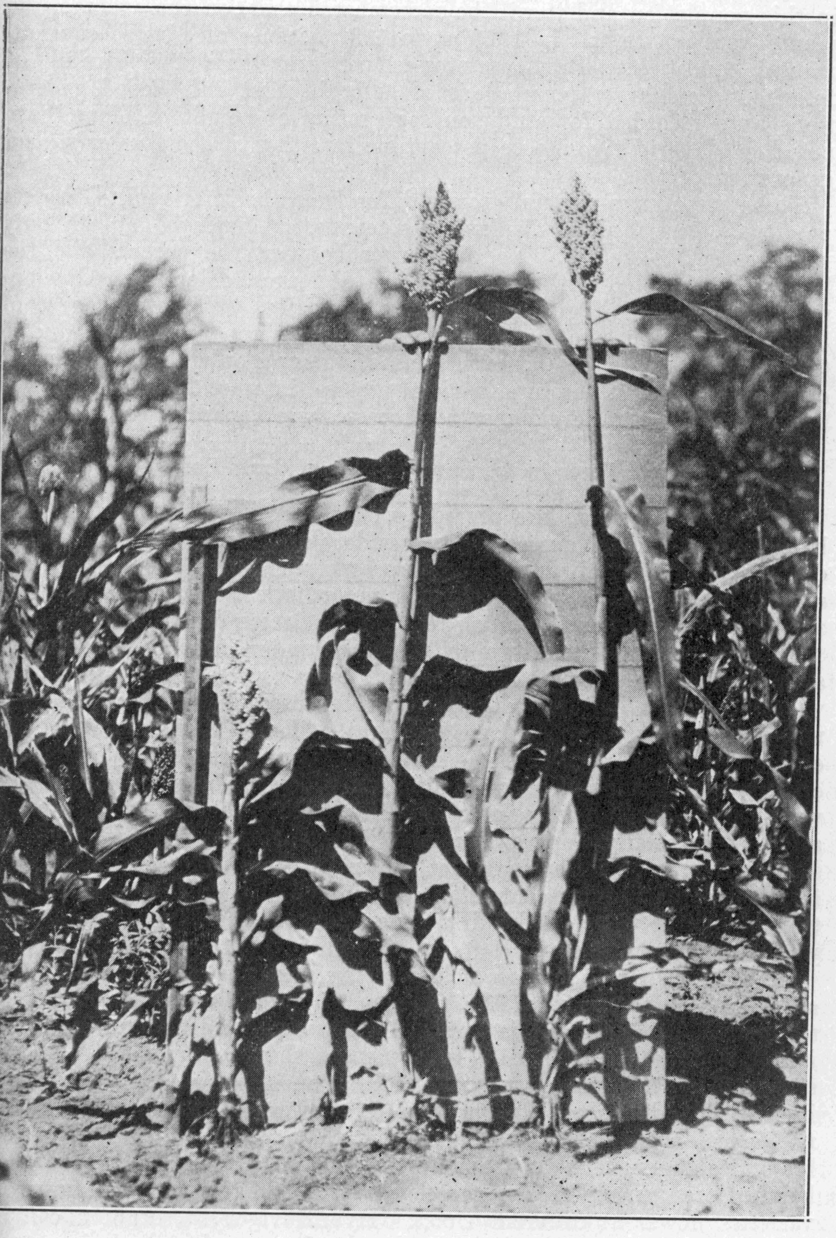
Cross V is between Extra Dwarf Yellow milo and Dwarf Yellow milo, two varieties apparently identical in every respect with the exception of height of plant. These parents differed in height by 20 centimeters, with the individuals in the tall classes of the dwarf parent overlapping with the shorter classes of the tall parent. Table 6 shows the distribution for the parents and the first- and second-generation progeny of this cross, together with the means, standard deviation, and cofficient of variability.

These two parents, although strains of the same variety, show rather marked hybrid vigor as measured by the height of plant, especially in the first generation of the cross. Although only four individuals were measured in the first generation, the increased height exceeded the tall parent by 20 per cent. The difference in height as exhibited between the tall parent and the F_1 generation grown in 1922 seems to be significant, being seven times as large as the probable error. The vigor in the second generation shows a marked decrease over that shown in the first generation and is an increase of 6 per cent over the tall parent. The difference in this generation, with a population of 366, is also significant, being six times as large as the probable error.

In the cross between Extra Dwarf milo and Dwarf milo, height is apparently due to several factors, the increased height shown in the F_1 being an expression of two or more complementary height factors, These two strains of milo seem to be identical in their genetic make-up with the exception of the factors for height. No other evidences of hybrid vigor were apparent.

In Cross VI, the parents involved are Extra Dwarf feterita and Standard feterita, being two strains of the same variety differing widely in height of plant. The tall parent exceeds the shorter by 69 centimeters, or is more than twice the height of the short parent. This cross between Extra Dwarf feterita and Standard feterita, two extremes in the feterita class (Fig. 4), affords a comparison with a similar cross, No. IV, between Extra Dwarf milo and Standard milo. The measurements on this cross are shown in Table 7.

The first generation shows an increase of 5 per cent over the tall parent, while the second generation shows an actual decrease of 13 per cent from the average height of the tall parent. Extra Dwarf feterita and Standard feterita differ genetically probably only in height. This difference has been found in unpublished data to be due to a single factor. The F_1 generation in this cross, therefore, merely exhibits simple dominance of the tall parent, the slight apparent increase in height over the tall parent probably being due to environmental influences affecting the single F_1 individual making up the sample. The decrease



g. 4.—Extra dwarf feterita (6312), left; standard feterita (1652), right, with F_1 hybrid in center. No hybrid vigor accompanies this cross.

in height shown in the second generation is due to the recessive dwarfs in this population and it will be remembered that, on the average, the plants were not as tall in 1923 as in 1922 because of adverse environmental conditions. Previous crosses between these two strains of feterita, when larger populations of both the first and second generations were recorded for study on segregation of height of plant, have not shown hybrid vigor to be perceptible in either of the first or second generation of this cross.

These three intra-varietal crosses differ from the inter-varietal crosses previously described in displaying heterosis, if displayed at all, only with respect to height. No differences between the parents and the hybrids were noted with regard to size of leaves, chlorophyll development, production of grain, or time of maturity. Whatever degree of heterosis has been exhibited in these crosses has apparently been due to the interaction of a few genetic factors affecting only the development of stature, while in the inter-varietal crosses, interaction of genetic factors affecting many developmental processes was apparently at play.

Hybrid Vigor in the Improvement of Grain Sorghum

It would seem from the preceding data and discussion that marked hybrid vigor attends crosses between widely different groups or between different varieties of grain sorghum, whereas, with crosses between strains of the same variety, hybrid vigor is not expressed, or to a smaller extent, depending upon the genetic factor differences involved.

Environmental factors were by no means under controlled conditions, and, furthermore, this work extended over two seasons with rather widely different effects upon the character used in this instance as a measure of hybrid vigor, namely, height. There is, therefore, considerable fluctuation shown in the height of plant between the first three crosses when strains of feterita, differing widely in height, were crossed with strains of milo, showing wide differences in height. This fluctuation is especially apparent in the first-generation hybrids, while a similar degree of variation is not shown in the second generation. It is possible that, under controlled environmental conditions, the exhibition of hybrid vigor in the first generation of these first three crosses would be more consistent.

In the growing of increase fields of pure seed, the breeder and grower alike are confronted with the problem of natural cross-pollination as the pollen from sorghum is carried by the wind, and absolute field isolation is difficult to obtain. In the event that nearby fields of other strains exist, the problem of cross-pollination in the seed fields becomes increasingly difficult. The breeder or grower of a seed field can do nothing to avoid cross-pollination other than to use every means possible to isolate such fields either by the separation from other strains or by the arrangement of his seed fields so as to have the two strains or varieties flower at different times. Hybrid vigor in sorghum can be used, however, to great advantage by the farmer who plants improved seed as a basis for the elimination of any first-year hybrids that occur in the field provided the breeder or grower of the seed from which his field was planted had taken the precautions necessary to have these hybrid plants express themselves in the form of hybrid vigor, thus allowing them to be rogued out of the field and entirely eliminated before they have caused any further contamination. This is possible in an effective manner, however, only where the grower has used precaution in planting adjacent only those varieties which when crossed are known to express hybrid vigor in the first generation. This simply means in practice that the breeder or grower of increase fields of sorghum should not plant strains of the same variety of sorghum adjacent, and that different varieties may be planted adjacent in seed fields with the certainty that any cross-pollination that occurs can be removed in the succeeding crop. The broader use of pure seed of strains free from contamination, therefore, is dependent upon the cooperation between the breeder, the seed grower, and the farmer who plants the seed.

The result of hybrid vigor in first-generation crosses between different varieties of sorghum is a marked increase in height of plant, size of leaves, and a corresponding increase in the size of the plant, including its yield of grain. (Fig. 5.) This increased yield due to hybrid vigor cannot, however, be put to economic advantage in sorghum, as is the case in corn, because of the difficulty in obtaining sufficient amounts of first-generation seed for field planting. The non-uniformity obtained in bulk second-generation seed is so great as to make the use of even second-generation seed, which retains some hybrid vigor, not acceptable for field planting by the farmer except possibly where the crop is used for silage.

Hybrid vigor is shown to be persistent in a considerable degree in the second generation, and has been observed to exist in grain sorghum in succeeding generations. The principal value attached to this phenomenon seems to be the unusual opportunity that exists for the breeder to select out of crossed materials recombinations, in later generations, which have inherited genetic factors contributing to hardiness, productivity, uniformity, earliness, and other desirable characters. Such recombinations recovered from wide crosses by the writers and now in the fifth and sixth generations show marked retention of hybrid vigor, even though it is not nearly so pronounced as in the first and second generations. More than fifty such recombinations have been grown and tested at the Lubbock Station, during the past five years, and they show a surprising uniformity, offering to the breeder unusual opportunity for obtaining new and desirable strains with stability of characters in such a degree as to make these recombinations entirely acceptable to farmers as varieties.

There are many varieties of grain sorghum in existence today which are known to be of chance hybrid origin, and probably many others not recognized now as of hybrid origin have come into existence by this means.

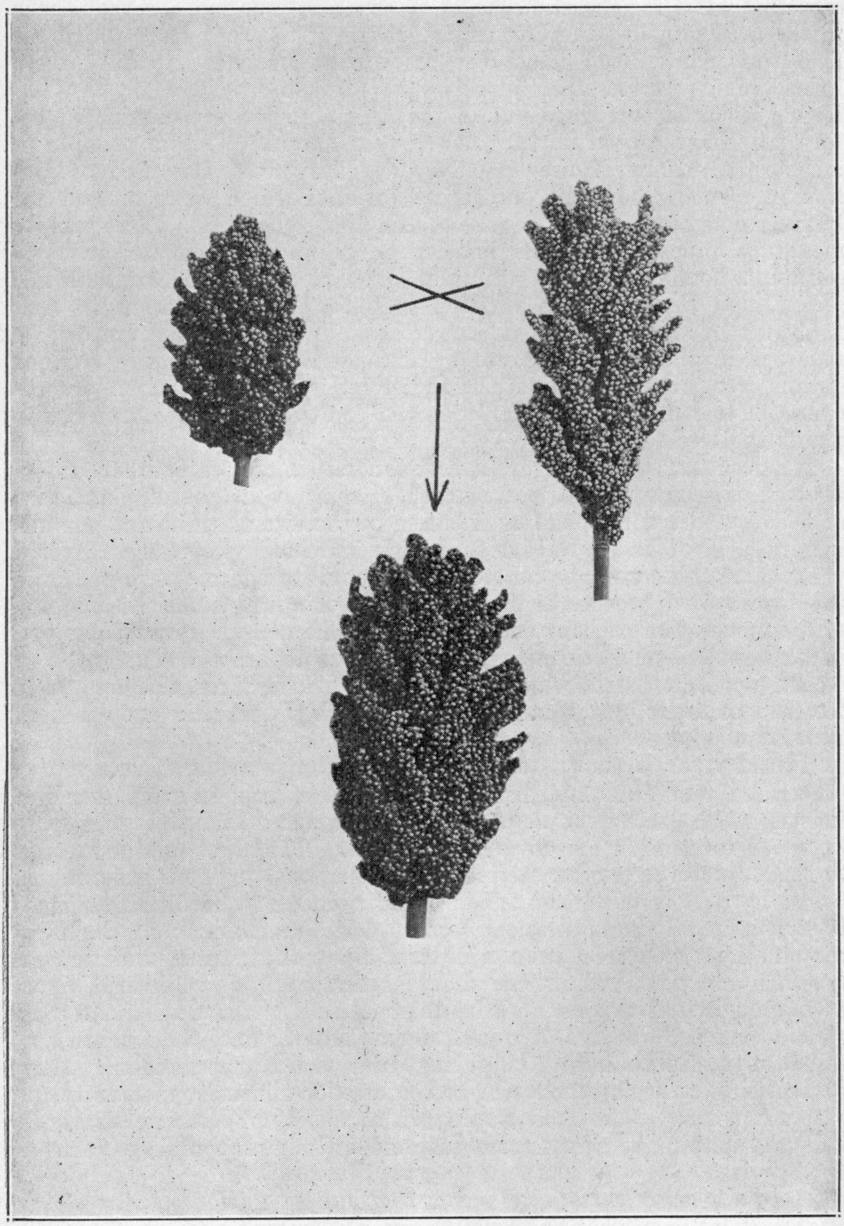


Fig. 5.—Crosses between widely related varieties of grain sorghum show marked increase in weight of plant and yield of grain in the first generation due to hybrid vigor. Head of dwarf yellow milo left, standard blackhul kafir right, and F_1 below.

Hegari has every characteristic of a hybrid between kafir and feterita, and although its origin is unknown, it is undoubtedly of hybrid origin. Sorghums cross-pollinate naturally to the extent of about six per cent under favorable conditions so that there is ample opportunity for the origin of natural hybrids. Many varieties which have appeared suddenly, such as Darso, Maizo, Shrock, and others, are from chance crosses. From these crosses have been recovered recombinations good enough to be considered varieties. Most of these have retained some degree of hybrid vigor. They are often good producers, but being of unselected parentages and in many cases crosses with sweet sorghums, they frequently inherit undesirable qualities, such as a high tannin content in the seed coat, as well as desirable. Premo and Chiltex, originating at the Chillicothe Station, are varieties which have been developed from artificial cross-pollination and they furnish examples of recombinations which can be removed from crosses of sorghum. There is a great diversity in types and variation of type from certain crosses, and especially those between different varieties. This great diversity of material possessing hybrid vigor which is carried over into succeeding generations offers unusual opportunity of originating and establishing new varieties in sorghum.

In crosses made between two inbred lines of kafir which had undergone eight generations of inbreeding no apparent evidence of heterosis was discerned, and, moreover, ten generations of inbreeding within a number of lines of kafir showed no perceptible reduction in vigor. Since crosses herein reported between closely related varieties, such as Dwarf milo and Standard milo, also do not display increased vigor, it would seem that any advantage in breeding or improvement of the crop which is to be gained by this phenomenon will have to come from wider crosses or crosses between groups more distantly related.

If the degree of expression of hybrid vigor may be taken as a measure of the relationship of the different varieties or groups of grain sorghums, this factor may lend itself to the working out of a better and more adequate key of classification than we have at the present time. For instance, feterita, having somewhat larger and more flattened seeds than kafir, is placed in the durra group along with milo. But hybrids between feterita and milo display unusual vigor, indicating that the two varieties differ in a great many genetic factors while hybrids between feterita and kafir are accompanied by hybrid vigor in a very much less marked degree. On the other hand, crosses between kafir and milo also show unusual vigor, frequently accompanied, however, by a decided lack in germination of the seed and by partial sterility, indicating, perhaps, an even more remote relationship. Some selections propagated into the third and fourth generations showed a range of sterility from five per cent to ninety-five per cent.

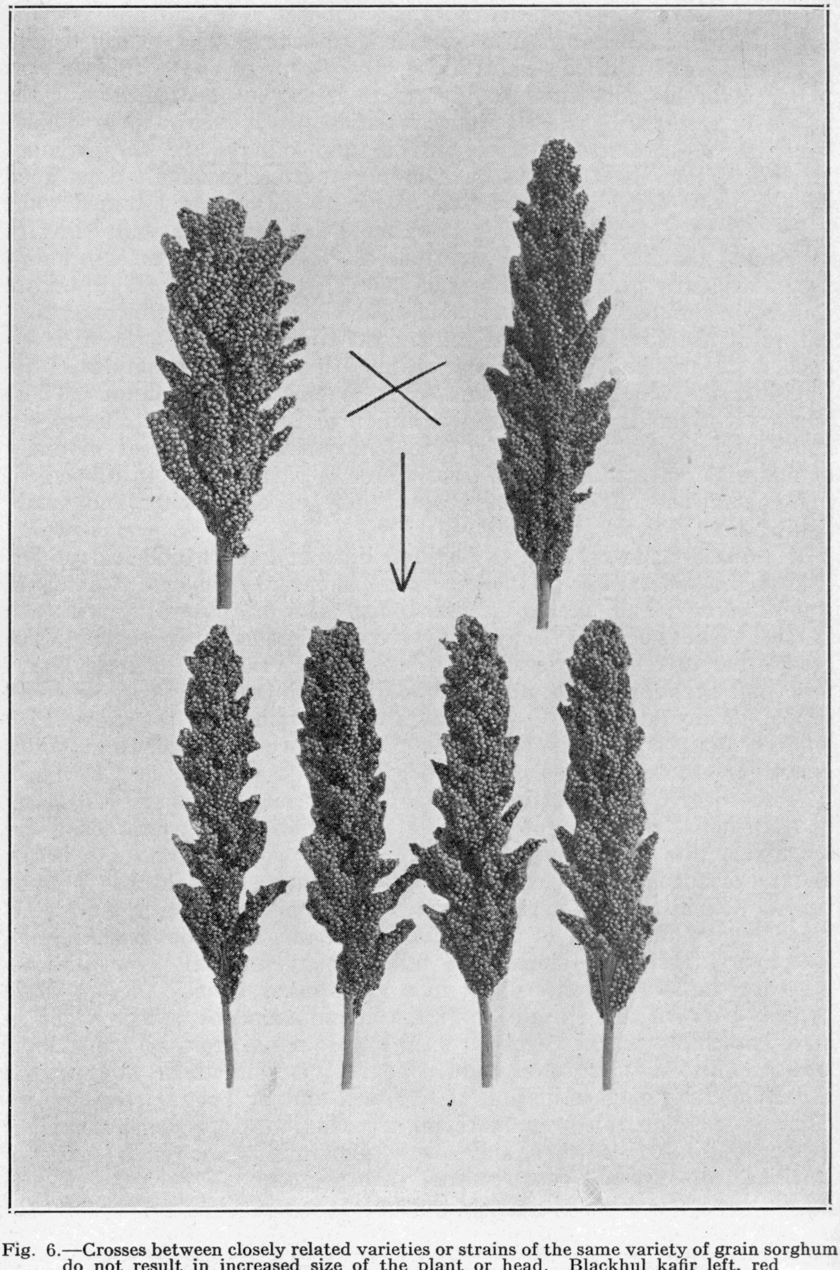


Fig. 6.—Crosses between closely related varieties or strains of the same variety of grain sorghum do not result in increased size of the plant or head. Blackhul kafir left, red kafir right, with four F_1 heads of this cross below showing dominance of the red kafir type of head but lack of increase in size over the parent.

SUMMARY AND CONCLUSIONS

1. A series of three varieties or strains each of milo and feterita having a corresponding common distinctive height and known as Extra Dwarf, Dwarf, and Standard afforded excellent material for measuring heterosis by the height of plant in crosses.

2. Marked hybrid vigor accompanied inter-varietal crosses between milo and feterita in both the first and second generation. In the three crosses between different varieties, the first generation showed an average increase of sixty-six per cent in height of plant over the tall parent. The corresponding second generations gave an increase of forty per cent over the tall parents.

3. Crosses between strains of the same variety where the parents differed apparently only in height of plant showed no hybrid vigor where the factors for height were due to a single factor and of the same allelomorphic pair. In a cross between Extra Dwarf and Dwarf milo complementary factors for height give an increase over the tall parent in both the first- and second-generation progeny.

4. An understanding of the expression of hybrid vigor in crosses between different sorghums is of value to the grower in keeping his seed pure and can be used to advantage in rogueing fields of pure strains.

5. Recombinations of desirable characters in individuals retaining hybrid vigor in later generations offer opportunity for breeding and improvement through hybridization and selection.

6. The degree of heterosis displayed when different varieties are crossed may be useful in determining the relationships of different types and in developing more adequate systems of classification.