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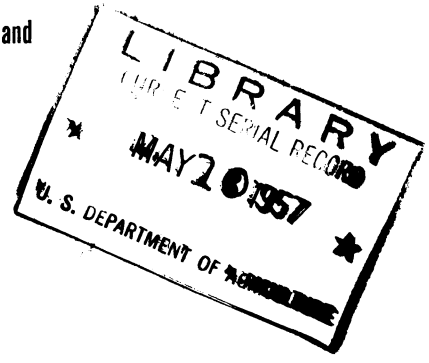

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DENT CORN INBREDS AND HYBRIDS

Resistant to the Corn Earworm in the South[1]

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United States Department of Agriculture in cooperation with the Mississippi Agricultural Experiment Station

The corn earworm (*Heliothis zea* (Boddie)) is one of the most destructive insect pests of corn, especially in the Southern States, where it seriously damages both dent and sweet corn every year. For example, 93 percent of the ears were infested, on an average, in 2 widely used varieties of open-pollinated dent corn during 1945–51 at State College, Miss. The average number of kernels destroyed per ear was 26. Based on the State's average yield of 20 bushels per acre over that period, this loss approximated 1,250,000 bushels for the 2,186,000 acres of corn grown annually for feed in Mississippi. The loss of sweet corn grown in the State for the commercial market in 1948 was estimated at about one-third of the crop, or about a hundred dollars per acre.

In addition to the amount of grain actually eaten by the earworm, damaged areas and emergence holes made by the larvae leave the ears accessible to disease organisms, the rice weevil (*Sitophilus oryza* (L.)), and other grain insects and liable to damage by birds and weathering (fig. 1). The earworm also injures corn foliage and tassels.

In a cooperative corn-improvement program by the United States Department of Agriculture and the Mississippi Agricultural Experiment Station, studies were undertaken from 1942 to 1951 to decrease losses caused by earworm damage to corn. This work consisted of breeding dent corn hybrids resistant to earworm injury, including the evaluation of inbreds and single- and double-cross hybrids for earworm resistance. It also entailed the isolation and improvement of resistant germ plasm and its transference to commercial hybrids, which offered an ideal solution of the earworm problem. Any increased yield obtained with earworm-resistant hybrids would profit the producer, since the cost would be no greater for growing resistant strains than susceptible ones.

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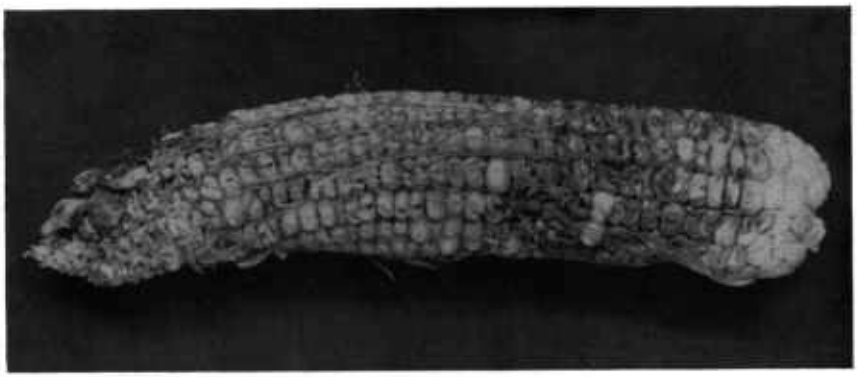

FIGURE 1.—Ear of corn damaged by the corn earworm, the rice weevil, and disease because of inadequate husk protection.

REVIEW OF LITERATURE

The resistance of dent and sweet corn to earworm infestation was first reported by Collins and Kempton (*2*) [2] in 1917. These workers showed that progenies of resistant parents had high percentages of uninfested ears and little damage from larvae in infested ears. Blanchard, Bigger, and Snelling (*1*) in 1941 reported that some inbreds transmit earworm resistance to single crosses. In the earlier literature earworm resistance was credited mainly to long husk extensions. Painter and Brunson (*5*) concluded that husk extension was not the only factor. Dicke and Jenkins (*3*) listed a number of Corn Belt inbreds that transmit earworm resistance to hybrids. They also reported that ears in resistant combinations had hard, starchy kernels and that earworm resistance was not always found in long-husked strains. In 1947 Douglas (*4*) indicated that length and tightness of husk extension could not be depended on to protect corn from earworm damage.

EXPERIMENTAL PROCEDURE

In the search for earworm-resistant corn, many data have been obtained from inbreds in various stages of development in the corn-breeding programs of the Southern States. The uniform tests sponsored by the Southern Corn Improvement Conference have been examined. Most of them have contained single crosses of the best new inbreds with the best old ones. In addition, data on some late Corn Belt inbreds have been obtained, as well as on strains from several foreign countries.

Most of the material examined has been grown at two or more of the experiment stations in Mississippi, usually the main station at State College and the Delta Branch Station at Stoneville. The early material was tested at Holly Springs and at State College or Stoneville. Corn has also been studied at five other experiment stations in the State, as well as on several delta plantations. Workers at the Alabama and Louisiana Agricultural Experiment Stations have grown many of the late-maturing single crosses for earworm studies.

[2] Italic numbers in parentheses refer to Literature Cited, p. 13.

Generally the corn was planted in 40- by 40-inch hills in 2- by 10-hill plots, thinned to 2 or 3 stalks per hill, and replicated 3 to 6 times at each of several locations. Entries were usually grouped into early, midseason, and late strains. The corn received ample fertilizer. It was cultivated in the usual manner and allowed to open-pollinate.

Resistance of corn ears to feeding by the earworm was one of the criteria used in selecting inbreds for further use in the breeding program at State College. Inbreds prepotent for earworm resistance were used, or they were crossed with inbreds superior in other characteristics but poor in earworm resistance. From such crosses inbreds were selected for earworm resistance, as well as for good yield, lodging resistance, and other desirable agronomic characters.

In these studies data were recorded for the usual agronomic characters and for husk extension beyond the tip of the ear, husk tightness, and insect damage to the ears. Where the infestation was severe enough, bud damage on young corn was sometimes noted. Data were also recorded on oviposition by the earworm moths on the silks in selected tests.

The corn in each plot was harvested separately, and each ear was rated as follows for earworm damage:

Rating	*Inches of damage penetration*	*Number of kernels destroyed per ear*
0 [1]	0	0
1	¼	1
2	¼–¾	11
3	¾–1½	34
4	1½–2½	95
5	Over 2½	150

[1] No infestation.

The average damage rating for each plot was determined by multiplying the rating by the number of ears given that rating, adding the products, and dividing by the total number of ears. From the average rating for each plot was obtained the average for the entry in the test. The percentage of infested ears was also calculated.

EVALUATION OF INBREDS

In 1943 a group of 405 inbreds were studied. Most of them were not vigorous and consequently had poor ear development, especially those prepotent for long husk. Data were taken on ear length, husk extension beyond the tip of the ear, husk tightness, and earworm damage. Husk extension ranged from −0.5 to +6.7 inches. The rating of earworm damage was difficult to determine because of the small number of well-filled ears and the failure of some inbreds to produce ears. Most of the inbreds that did not have enough ears to permit an earworm rating were badly damaged by the insect. There was no significant correlation between husk extension and earworm damage.

In 1947 another group of 314 inbreds were tested, with results similar to those obtained in 1943.

From the data on both groups it was concluded that inbreds in themselves were unsatisfactory for the study of earworm resistance.

Tests of hybrids run concurrently with the tests of inbreds making up the hybrids indicated that the value of an inbred in breeding for resistance can be more reliably and accurately determined by rating the hybrids because of their greater vigor and more normal development. Therefore, the practice of rating inbreds for damage was discontinued in 1947, and hybrids were used to determine the prepotency of inbreds for earworm resistance. Single-, double-, 3-way, and top-cross hybrids were checked, but almost all the data given here were based on single-cross hybrids.

EVALUATION OF INBREDS IN HYBRID COMBINATIONS

Many inbreds were rated for resistance to the corn earworm in the tests of hybrids in Mississippi, Alabama, and Louisiana from 1943 to 1951. Before an inbred was given a definite rating, it was tested in combination with other inbreds in at least 6 replications in 2 or more locations. Therefore, although there has been some variation in the intensity of the infestation, the possibility of error in rating has been reduced to a minimum. Although most inbreds were rated on their reactions in single-cross combinations, double-cross hybrids were also observed, even though it was difficult to trace the influence of any 1 inbred where as many as 4 inbreds were involved.

The data for the inbreds, based on their performance in hybrid combinations, have been arbitrarily divided into four resistance categories, which are described as follows:

Resistance category	*Rate of larval establishment in ears*	*Amount of damage to ears*
Highly resistant	Low	Slight.
Resistant	Moderate	Slight.
Intermediate	Moderate	Moderate.
Susceptible	High	Severe.

The following inbreds have been classified according to these resistance categories:

Resistance category	*Inbred*
Highly resistant:	
White	F1, F2, L501, L503, Mp313
Yellow	F6
Resistant:	
White	F3, F4, GE205, GE247, GT1, HK61, L87, L95, Mp309, Mp331, Mp335, T101
Yellow	F8, F44, Mp1, Mp410, Mp426
Intermediate:	
White	GT3, GT5, L2–2, L10, L25, L44, L90, L91, Mp305, Mp311, NC33, NC34, NC37, NC45, NC74, NC75, R30, Tx61M, 1112.4, 1133.28, 1134.35
Yellow	CI.7, F5, F7, GE38, GT169a, GT169b, GT175, Kls49, Kls50, KY35–7, KYS, L101, L510, L515, L578, Mp402, Mp412, Mp414, Mp428, NC7, NC13, NC82, NC83, O–18, T204
Susceptible:	
White	C66, CI.23, H–21, H–22, H–H–202, K44, K55, K64, K122, Ky13, Ky27, Ky49, Ky58, Ky89, Ky124, L13, L24, L25, L62, L86, L103, Mo21A, Mo22, Mp301, Mp303, Mp307, Mp315, Mp317, Mp319, NC39, NC44, R7, R11, R17, R23, T10, T13, T14, T18, T61, T83, T85, T105, T111, T113, T115, T155A, 33–16, 5340, 5376, 5389, 5434, 5437

Resistance category	*Inbred*
Susceptible—Continued	
Yellow	CI.21, F51, F64, GT22, GT112, GT152, GT154, K4, K155, K201–C, L540, L548, L569, L575, L586, L587, L588, L589, Mp412, O–14, O–14T, O–19, O–52, R34, R37, R40, T8, T202, 5428

In addition to the preceding inbreds, many experimental and Corn Belt inbreds and those from other sources were tested and discarded because of susceptibility or agronomic reasons; therefore, they were not included in this list.

When evaluated on the basis of tests with single crosses, some inbreds showed specific combining ability for earworm resistance. Some inbreds were highly resistant in certain single crosses, but they were much less resistant in other single crosses. The explanation may be that earworm-resistant factors are due to a number of genes. For example, as shown in table 1, the inbred T204 has an average damage rating of 1.91, which is low, but it has not been consistent in its performance with other inbreds. It was very good with Mp410 and very poor with Mp426. The resistance of an inbred of this type cannot be predicted on the results obtained by crossing it with another inbred of known value. On the other hand, CI.21 crosses are generally toward the susceptible end of the scale, whereas Mp410 crosses are generally toward the resistant end. Both CI.21 and Mp410 are general combiners.

TABLE 1.—*Corn earworm damage ratings* [1] *of single crosses of a resistant, an intermediate, and a susceptible yellow inbred among each other and 11 other yellow inbreds in tests at State College, Miss., 1943–51*

Inbred	Resistant Mp410	Intermediate T204	Susceptible CI.21
	Rating	*Rating*	*Rating*
Resistant:			
Mp1	0. 99	1. 52	1. 88
Mp410	----------	. 91	2. 03
Mp426	1. 52	2. 45	2. 66
Intermediate:			
Kls49	1. 40	1. 39	2. 57
Kls50	1. 65	2. 21	2. 89
Mp412	1. 14	2. 03	2. 19
Mp414	1. 21	1. 85	2. 32
Mp428	1. 61	1. 90	2. 51
T204	. 91	----------	2. 41
Susceptible:			
CI.21	2. 03	2. 41	----------
GT112	1. 91	2. 23	2. 90
Others:			
Kls27	1. 61	1. 64	2. 68
Kls143	1. 72	2. 06	2. 82
Mp440	1. 90	2. 25	2. 78
Average	1. 51	1. 91	2. 51

[1] 0=no infestation. For complete explanation, see p. 3.

The inbred CI.7 is classified in the preceding list as intermediate in susceptibility to the earworm, whereas Dicke and Jenkins (*3*) listed

it as consistently transmitting to hybrids ear qualities that gave good protection against earworm damage. These observations indicate that the heavy earworm damage in the Gulf Coast States gives a more severe test for resistance than in areas where the earworm is not so abundant and that material showing resistance under a light infestation may not give resistance under a very heavy infestation.

In 1946 the double-cross hybrid La. 1030 showed resistance in all test plots at 7 locations in Mississippi and 2 in Louisiana. In 1947 all possible combinations of the inbreds that make up this hybrid were tested at State College to determine which inbreds contributed earworm resistance. The data on these inbreds and on La. 1030 and the double-cross hybrid Dixie 17, used for comparison, are given in table 2. The inbred L503 was found to be the most resistant and L501 slightly resistant.

TABLE 2.—*Corn earworm damage ratings* [1] *and percentages of ears infested of 4 inbreds of La. 1030, as expressed in their single-cross progenies, and of the double-cross hybrids La. 1030 and Dixie 17 in tests at State College, Miss., 1947*

INBREDS OF LA. 1030 [2]

Entry	L501		L503		L548		L569	
	Earworm damage rating	Ears infested	Earworm damage rating	Ears infested	Earworm damage rating	Ears infested	Earworm damage rating	Ears infested
		Percent		*Percent*		*Percent*		*Percent*
L501			0. 54	39	1. 28	75	1. 34	73
L503	0. 54	39			. 84	58	1. 05	66
L548	1. 28	75	. 84	58			1. 84	83
L569	1. 34	73	1. 05	66	1. 84	83		
Average	1. 05	62	. 81	54	1. 32	72	1. 41	74

HYBRIDS

Entry	Earworm damage rating	Ears infested
		Percent
La. 1030	1. 38	76
Dixie 17	2. 00	95

[1] 0=no infestation. For complete explanation, see p. 3.
[2] Least significant difference at the 5-percent level is 0.42.

Ten white inbreds, including L501 and L503, were tested in al possible single crosses at Natchez, Miss., in 1948. The data are shown in table 3. The high resistance of L501 and L503 is clearly demonstrated. Almost every cross with L501 or L503 had a lower earworm damage rating than crosses with any of the other inbreds.

TABLE 3.—*Corn earworm damage ratings* of 10 white inbreds, as expressed in their single-cross progenies, in tests at Natchez, Miss., 1948* †

Inbred	F2×33 [2]	Mp309	Mp307	914.2–2–B	2.210–1–B	Mp301	Mp311	NC45	L501	L503
	Rating	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
F2×33 [2]	---	1. 57	1. 60	1. 67	2. 62	2. 76	1. 74	1. 54	1. 23	0. 62
Mp309	1. 57	---	1. 17	(‡)	1. 35	2. 74	2. 35	2. 46	. 96	1. 05
Mp307	1. 60	1. 17	---	1. 35	1. 40	2. 21	2. 17	2. 05	1. 13	. 99
914.2–2–B	1. 67	(‡)	1. 35	---	2. 57	2. 83	2. 13	1. 61	. 98	1. 00
2.210–1–B	2. 62	1. 35	1. 40	2. 57	---	3. 99	1. 63	3. 40	2. 14	. 77
Mp301	2. 76	2. 74	2. 21	2. 83	3. 99	---	2. 61	2. 58	1. 99	1. 52
Mp311	1. 74	2. 35	2. 17	2. 13	1. 63	2. 61	---	1. 88	(‡)	1. 68
NC45	1. 54	2. 46	2. 05	1. 61	3. 40	2. 58	1. 88	---	1. 00	. 81
L501	1. 23	. 96	1. 13	. 98	2. 14	1. 99	(‡)	1. 00	---	. 75
L503	. 62	1. 05	. 99	1. 00	. 77	1. 52	1. 68	. 81	. 75	---
Average	1. 71	1. 71	1. 56	1. 77	2. 21	2. 58	2. 02	1. 93	1. 27	1. 02

* 0=no infestation. For complete explanation, see p. 3.
‡ Least significant difference at the 5-percent level is 0.47.
† Seed not available.

In these same tests an open-pollinated variety and five double-cross hybrids were used as checks. Their earworm damage ratings were as follows:

Entry	*Pedigree*	*Earworm damage rating*
Station Mosby	Open pollinated	3. 07
Dixie 17	(T61 × T13) × (NC37 × NC34)	2. 48
Dixie 18	(F44 × F6) × (GT112 × L578)	1. 48
Dixie 11	(Tx61M × L10) × (L2–2 × L44)	1. 43
La. 1030	(L501 × L503) × (L548 × L569)	1. 13
Miss. 8011	(L501 × L503) × (F44 × F6)	. 86

Station Mosby and Dixie 17 were classified as susceptible, whereas the others were resistant. Dixie 18, Dixie 11, and La. 1030 have been released for commercial production.

Dixie 17 is a white hybrid that yields well. It is susceptible to both the earworm and the rice weevil, but it has been used successfully in the northern part of the Gulf States, Tennessee, and North Carolina.

Dixie 18 is a yellow hybrid that yields well, is resistant to both the earworm and the rice weevil, and has excellent quality of grain. It is the leading yellow hybrid of the South. It is composed of 1 highly resistant, 1 resistant, 1 intermediate, and 1 inbred susceptible to earworm damage. Attempts have been made to replace GT112, which is the susceptible inbred, with a resistant inbred, but GT112 contributes such characteristics to the double cross as desirable ear size and good yield, which make it indispensable at present.

Dixie 11 is a white hybrid, having intermediate resistance to both the earworm and the rice weevil. It yields well and produces good-quality corn.

La. 1030 has many excellent qualities. It yields well, stands well, and has earworm resistance that closely approaches immunity, rice weevil resistance, and top-quality grain. Its resistant inbreds—L501 and L503—are maintained as a source of resistant germ plasm. However, when these inbreds were put out on a field basis for single-cross production as a seed parent for the hybrid, the yields were so low that La. 1030 could not be produced commercially.

Miss. 8011 has many of the desirable characteristics of La. 1030, but it was not released for commercial production because of the poor yield of L501 and L503 as producers of single-cross seed.

La. 521 is a white hybrid of good quality, fair yield, and medium earworm and rice weevil resistance. It is derived from 4 inbreds that have been rated intermediate for earworm resistance. All parents—(L90 × L91) × (L44 × L2–2)—rate at the top of the intermediate group, being almost good enough to be included in the resistant group. This is the only commercial hybrid in production that has 4 intermediate inbreds in its pedigree. Its earworm damage rating compares favorably with that of Dixie 18. La. 521 is used throughout the rice weevil belts of Louisiana, Mississippi, Alabama, and Georgia.

Two resistant inbreds combined into a single-cross parent sometimes give high earworm resistance. Dixie 18 has 1 highly resistant inbred and 1 resistant inbred in the seed parent F44 × F6. In La. 1030 the single cross L501 × L503 contributes resistance. Six double-cross hybrids having L501 × L503 as 1 parent were all resistant to the earworm. Their earworm damage ratings and those for Dixie

17 and the open-pollinated variety Station Mosby tested in 3 locations in Mississippi are as follows:

Place tested and entry	*Earworm damage rating*
Natchez:	
(L501 × L503) × (Mp313 × NC45)	0. 25
(L501 × L503) × (L548 × L569)	. 27
(L501 × L503) × (Mp309 × NC45)	. 40
(L501 × L503) × (Mp313 × 1134.35)	. 86
Yazoo City:	
(L501 × L503) × (F44 × F6)	1. 40
Dixie 17 (T61 × T13) × (NC37 × NC34)	1. 78
Station Mosby	2. 65
Stoneville:	
(L501 × L503) × (Mp1 × Mp412)	1. 16
Station Mosby	2. 50

Although the inbreds L501 and L503 are very poor producers and are not suitable for use in a commercial hybrid, the single cross itself has a fine-looking ear, high-quality corn, and high earworm resistance (fig. 2). Either inbred crossed with another inbred improves

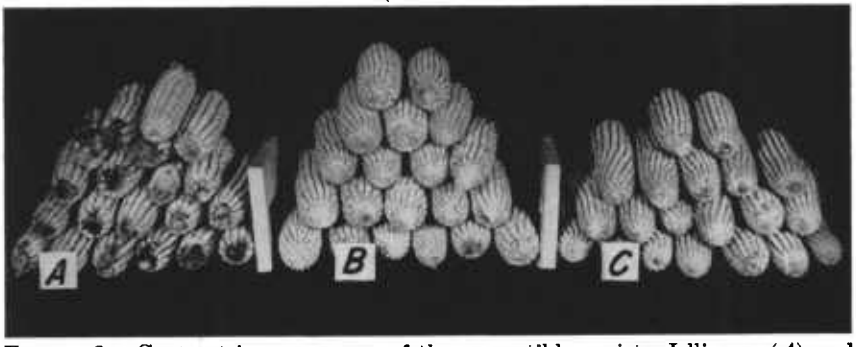

FIGURE 2.—Contrast in appearance of the susceptible variety Jellicorse (*A*) and the resistant single crosses L501 × L503 (*B*) and L503 × F1 (*C*).

the quality and earworm resistance in the single cross. Therefore, each of these inbreds provides a valuable source of resistant germ plasm, which should be maintained and used to produce inbreds that will improve susceptible commercial inbreds. L503 × F1 is a highly resistant single cross (fig. 2, *C*). F44 × F6 and L501 × L503 have practically no earworm damage as compared with such susceptible strains as Jellicorse (fig. 2, *A*).

Good sources of earworm-resistant germ plasm are to be found in other single and double crosses. For example, Mp410 came from F6 × F7, a resistant single cross, and Mp331 from Fla. W1, a resistant double cross. These inbred progenies have agronomic advantages over any of the parents and are equal or superior to them for earworm resistance.

Several other white inbreds carry considerable earworm resistance and are used in commercial hybrids. They are F1, F2, F3, F4, T101, and L87. Three white single crosses (fig. 3) illustrate the possibilities of using earworm-resistant single crosses in double-cross hybrids. T101 × Mp303 and T101 × Mp309 have earworm resistance, as well as other desirable characteristics. They have rather large thick seeds, which are not desirable in a seed parent, but they might be used to

good advantage as pollinators. Mp331 × Mp305, which has also shown resistance, has uniform seeds and is well suited for a seed parent.

Earworm resistance in the yellow inbreds has not been found to equal that in the white inbreds. The yellow single cross F44 × F6 has been excellent. It is the seed parent for the resistant hybrid Dixie 18. Some of the new inbreds in single-cross combinations also show promise.

The yellow single cross Mp1 × Mp410 has earworm resistance and is excellent for a seed parent. The yellow single cross Mp426 ×

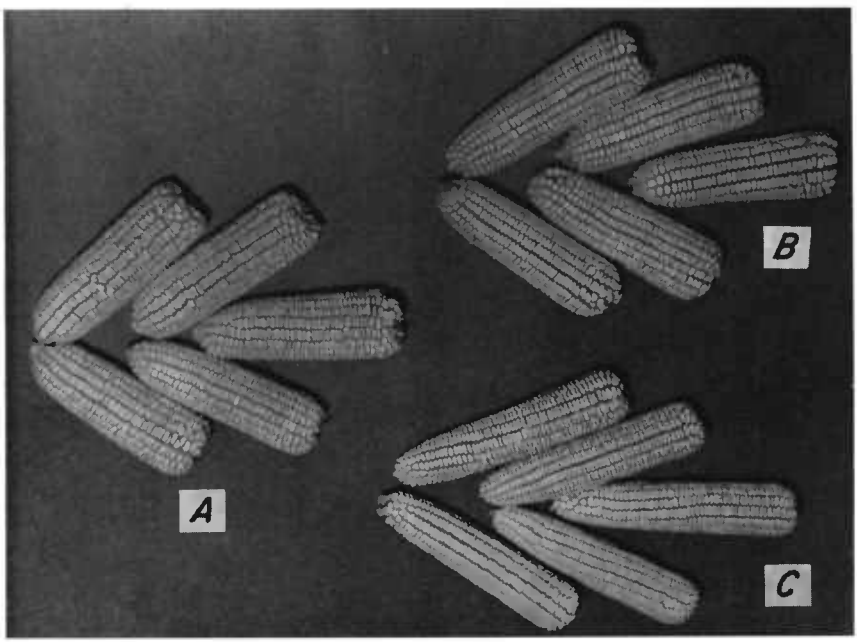

FIGURE 3.—Three white single crosses showing earworm resistance: T101 × Mp303 (*A*) and T101 × Mp309 (*B*), suitable for pollinators, and Mp331 × Mp305 (*C*), suitable for a seed parent.

GT112 has possibilities as a pollinator. The resistance in Mp426 overcomes susceptibility in GT112, which has high yield and thick kernels. (Fig. 4.)

Figure 5 shows an earworm-susceptible double-cross hybrid, which may be compared with the earworm-resistant single crosses in figures 2–4. Although this hybrid is not the most susceptible, it indicates the improvement made through selection and combination of certain inbreds resistant to earworm damage.

Some husk protection is essential for a good southern hybrid. However, an extremely long husk is not necessary or even desirable in an earworm-resistant hybrid. A tight husk extension of approximately 2 inches, as in the single cross L501×L503, appears ample for protection from the rice weevil, pink scavenger caterpillar (*Pyroderces rileyi* (Wlshm.)), birds, and weathering. When the ears are exposed, earworm damage is usually greater, and these insects, as well as several

scavenger flies and beetles, infest the ears. Earworm feeding gives entrance places for diseases to develop, which cause kernel decay. This unhealthy condition is attractive to insects.

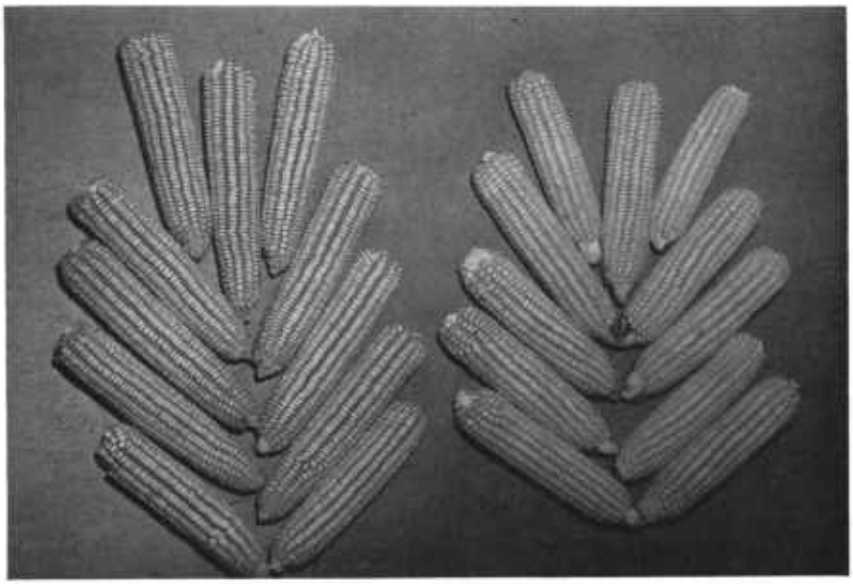

FIGURE 4.—Two yellow single crosses showing earworm resistance: Left, Mp1 × Mp410; right, Mp426 × GT112.

DETERMINATION OF VALUE OF RESISTANT HYBRIDS

To illustrate how losses due to the corn earworm may be reduced through development of resistant hybrids, an evaluation was made of damage to 1 open-pollinated variety and 3 hybrids. The earworm damage ratings and the losses in kernels per ear and yield per acre are shown in table 4.

TABLE 4.—*Correlation between corn earworm damage ratings* [1] *and losses caused by the earworm to 1 open-pollinated variety (Station Mosby) and 3 hybrids in tests at State College, Miss., 1943–51*

Entry	Earworm damage rating	Loss in—	
		Kernels per ear [2]	Yield per acre [3]
		Percent	*Bushels*
Station Mosby	3. 07	6. 4	3. 2
Dixie 17	2. 48	3. 7	1. 85
Dixie 18	1. 48	. 97	. 48
La. 1030	1. 13	. 38	. 19

[1] 0=no infestation. For complete explanation, see p. 3.
[2] Based on 600 kernels per ear.
[3] Based on 50 bushels per acre and percentage of kernels damaged.

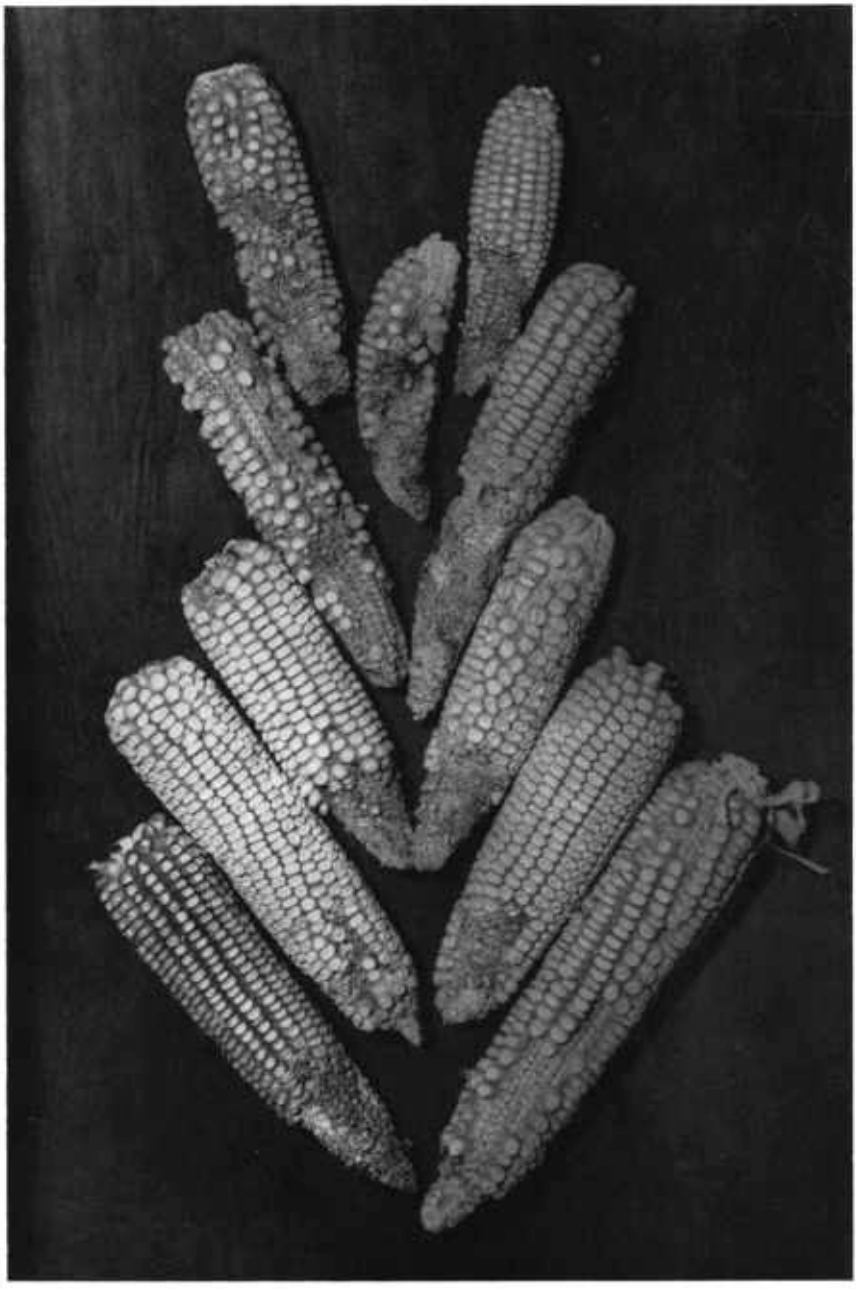

FIGURE 5.—Ears from a susceptible double-cross hybrid, showing severe injury by the corn earworm.

The percentage of kernels damaged by the earworm in Dixie 18 was only about one-sixth of that in Station Mosby. Earworm loss to La. 1030 was negligible. In addition to direct loss in yield due to the earworm, the earworm-susceptible hybrids showed further losses from rice weevil infestations and from ear rots, which often follow earworm infestation.

SUMMARY

In the South losses due to the feeding of the corn earworm (*Heliothis zea* (Boddie)) on ears of corn amount to millions of bushels annually. A cooperative program was undertaken by the United States Department of Agriculture and the Mississippi Agricultural Experiment Station from 1942 to 1951 to decrease these losses through the breeding of dent corn hybrids resistant to earworm injury. Data were obtained on earworm damage in inbreds, through rating of their performance in single crosses, and in single- and double-cross hybrids.

Five highly resistant white inbreds—L501, L503, F1, F2, and Mp313—and a highly resistant yellow inbred—F6—were found that transfer their resistance to their single-cross progenies. Twelve white inbreds and 5 yellow inbreds were classified as resistant. In addition, the susceptibility of many other inbreds to earworm damage was determined through studies of their performance in single crosses.

Commercial hybrids with earworm resistance that are now widely grown are Dixie 18, Dixie 11, and La. 521. Experimental data show that earworm damage to Dixie 18 is only about one-sixth of that to Station Mosby.

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