DIFFERENTIAL RESISTANCE AMONG VARIETIES LINES AND COMBINATIONS OF LINES OF CORN TO HELIOTHIS ARMIGERA (HBN.)

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Introduction

The necessity for accumulating data in regard to earworm resistance in corn that would be valuable in corn breeding work stimulated this investigation. This study is devoted to measuring the differential variation in resistance to earworm attack of lines and varieties and combinations thereof that are being used in the corn breeding program at the Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma. A multiple correlation study was made of the factors affecting earworm resistance in corn and the effect each factor has singly in rendering the hybrid or variety resistant to earworm attack.

Attention was given to the prepotency of the lines in transmitting resistance to earworm damage, and plant characters associated with resistance, in combination with other lines.

One of the most destructive insect pests in the United States is the corn earworm (Heliothis armigera (Hbn.)). Every corn grower is familiar with this insect, but few realize the extent of its depredations. According to Phillips and Barber(33), the total damage caused annually by this insect is conservatively estimated at $40,000,000 and the American farmer grows, on an average, approximately 2,000,000 acres of corn each year to feed the earworms. This loss does not include that caused indirectly by the insect such as the organisms that attack the ear after the earworm has made an entrance, greater losses by weevils and other insects through these same previous entrances, and ears that do not develop because the earworm has cut the silks off, thus preventing fertilization, Kyle(29).

The losses suffered from this insect increase from north to south.

The winters in the northern corn growing regions are rigorous enough to prevent the survival of a large enough population of the pupae to cause a severe infestation the following year however, the damage is occasionally serious. In the more southern regions, the pupae are better able to survive the milder winters. They are also benefited by the presence of their most important secondary host, cotton. In some of the southernmost regions, it is impractical to grow sweet corn which is particularly susceptible to the ravages of this insect. Field corn, being a more resistant crop, is being grown in order to supply the table needs.

Although hibernating populations are substantially reduced by soil tillage in the fall and winter, a high percentage of corn ears become infested in areas where climate, soil, and cultural conditions allow the pupae to survive the winter in considerable numbers. While cultural means of control are effective and should be practiced whenever economical to do so, it is impossible to suitably control the earworm by this means because these cultural practices are not consistently followed throughout the region, and in addition all of the earworm larvae do not pupate in places where the soil can be cultivated. Ditman and Cory (21) show that earworm populations can be appreciably reduced by the use of poison baits. However, since the unit value of corn is small and the acreage large, the use of insecticides has proven impractical as a means of control. In recent investigations much effort has been concentrated on reducing these losses directly through the discovery and utilization of resistant strains of corn.

The usually mild winters of Oklahoma and perhaps the tendency for farmers to plant repeated successions of corn on the limited acreages adapted to the raising of corn result in a large population of corn earworm moths each spring. These moths lay a multitude of eggs on the silks as soon as they appear. Those eggs which escape their enemies may hatch and the larvae will be present to attack the ears. A large population of moths is reflected in the fact that an ear entirely free of damage is rare. Although Burk, Cross and Hixon (12) ran a varietal test on sweet corn resistance to corn earworm damage in Oklahoma, and later other investigators (10) conducted a similar study on a field of white corn, there remains much to be done in discovering resistant lines for use in future hybrids for Oklahoma. Because of the high degree of infestation and the large recurrent losses in Oklahoma, this state seems to be a logical place for corn strains with germ plasm which has the necessary genes to produce a hybrid that is resistant to earworm ravages in conjunction with other desirable agronomic characters. Not only should the incentive be greater, but it seems that Oklahoma is the natural testing ground for breeding work of this nature. To add to the feasibility of Oklahoma developed resistance to corn earworm damage, the necessary longer and tighter husk is found in the southern varieties. According to Kyle (20) this condition of the husk is a result of natural and intended selection.

It appears probable that Oklahoma will become one of the ranking hybrid seed corn producers in the nation. Because of the long growing season in the south, there is no difficulty experienced in getting seed corn to mature. The longer growing season may prove attractive enough for the large hybrid seed corn producers of the north to begin production in the south. Until resistance to earworm damage can be bred into the lines that go into the hybrids, growers will sustain considerable losses in seed corn production.

Review of Literature

The literature relevant to earworm resistance in sweet corn is more voluminous than that of field corn because sweet corn has a higher unit value, is less resistant and earworm damage renders it almost useless for market. Consequent to the high loss per unit area in sweet corn, the incentive for experimentation has been higher. The factors rendering sweet corn resistant are found to exist in field corn and have the same relationship in producing resistance. After consideration of these facts, it appears desirable to review the literature on earworm damage in sweet corn in conjunction with that of field corn.

Garman and Jewett (25) give the life history and habits of the corn earworm, some of the secondary hosts and the natural enemies that counteract the full damage that could be caused in the absence of the natural enemies. Phillip and Barber (33) discuss the different types of earworm damage, other insects causing similar injury to corn, the stages of the earworm and seasonal history. Also, the natural limiting factors which include cannibalism, parasites and predacious enemies, weather conditions, disease and the importance of natural agencies. Methods of limiting damage to field corn by the time of planting, character of the husks, soil productiveness and plowing are discussed as well as the possible degree of control. In another paper (36) these workers give a detailed account of the time and placement of the eggs by the earworm moth, oviposition in relation to the various growth periods of the corn plant, oviposition in relation to planting date of corn and variation in attractiveness of silks for oviposition at different stages. They state that eggs are laid on the corn plant from the last of May to October and as a rule, the largest number of eggs are deposited on the plants of late plantings, while those of the midseason plantings received the least number of eggs; that moths prefer the moist silks for oviposition and that silks were most attractive to the moths the third day after they were exposed; eggs were deposited on all parts of the plants before the silks appeared. Their work shows only a small percentage of the eggs laid hatch. Fewer eggs hatch as the season progresses. Cannibalism among the earworm larva and the effect it has on damage is reported by Barber (1). He correlates husk characteristics with cannibalism finding that more cannibalism takes place in the long, tightly fitting husk, thus leaving fewer larvae to attack the ear.

Barber (3) records the number of eggs laid by the corn earworm moth. He found that eggs were deposited on all parts of the plant during all stages of growth; that larvae feed on whatever part of the plant that is most attractive at the time of hatching; and that such larvae may migrate to the silks and may enter the ear before dust or sprays can be applied.

Studies of the effect of temperature and moisture were conducted on the overwintering pupa in the northeastern states by Barber(4). He gives the freezing point of the larva at different humidities and fat analysis of the pupa at different periods during overwintering. He found that some of the pupae were able to float in water and that these were the ones which survived when the ground was saturated with water, filling the chambers in which they were pupating. Dicke (18) correlates the damege of different plantings with the seasonal abundance of the moths that were active at the time the silks were fresh.

Barber (7), studying the hibernation of the corn earworm in southeastern Georgia, found that 75 percent of the larva completing the life cycle in the same year in which they were hatched lived, and 51 percent of those hibernating over winter survived. He found that larvae dig from one to ten inches deep to pupate, and the depth to which they dig is determined to a great extent by the length of the pupation. Three types of emergence were recognized: immediate, delayed in the same year, and delayed until the following year. Haseman (26) tells of a serious outbreak of earworms in Missouri with reference to the over-wintering of the insect in Missouri and the migration of the moths from the south. Some of the hosts are also listed. Estimates of the number of generations of earworms annually have been reported as four in Arkansas by Isely (29), four to seven in the cotton belt by Quintance and Bishop (39), and three to four in Kansas by Headlee (28).

The relative effectiveness of some corn earworm control measures reported by Davidson (17), show 91.7 percent clean ears on plots treated with mineral oil-styrene dibromide, 81.6 percent with mineral oil-pyrethrin, 61.0 percent on the plots in which the silks of the ears had been clipped, and 21.3 percent on untreated checks. With mineral oil alone or in combination with insecticides, Barber (5) found an effective barrier in the corn with fairly tight husk. The use of a regular oil can in applying the oil to the silks was thought to be as good as the hypodermic needle. Two-tenths of 1 percent pyrethrin in the mineral oil was found to be the most practical concentration for commercial use.

Wilcox (40) recommends the rate of application and strength of cryolite dust mixtures should be controlled by the value of the crop and severity of infestation. Barber's (9) tests show a saving in cost of earworm control by the replacement of pyrethrine in oils by dichloroethyl ether. Wilcox (41) found that 80.0 percent of the earworm damage could be avoided by the use of insecticides. Carruth and Kerr (14) found that the moths were attracted to some lights to a small extent, but concluded that light traps could not be effectively used as a control.

Phillip and Barber (34) conducted experiments to determine if there is a period during which field corn can be planted in central Virginia in order to escape severe earworm injury. They found that: the average number of kernels destroyed was least in the earliest planted plots and fields and the greatest in those planted on the latest dates; no definite relationship exists between the size of the field and the degree of earworm damage; and that earworms do not feed more extensively on the small ears than on the large ones, but the loss of weight in the small ears was greater.

Ditman and Cory (21) suggest fall plowing to destroy and expose hibernating pupa to the birds and weather. They also recommend early planting to allow corn to silk ahead of the height of the moth population. Dicke and Barber (19) published data pertaining to husk characters of field corn in relation to the feeding of birds on the earworms. From their observations, they conclude that birds decrease the variability that might be shown in strains by removal of worms from short-husked strains.

Collins and Kempton (16) were among the first investigators in the field of earworm resistance. By crossing the sweet corn varieties with resistant field corn varieties, they were able to select in the F_2 a sweet corn type having a higher degree of earworm resistance than the sweet parent. They found more correlation between husk prolongation and resistance than in any of the other factors affecting resistance. Manglesdorf (31) working with sweet corn found that resistance could be bred into the varieties by crossing them onto resistant field corns, especially some of the exceptionally long husked varieties.

Poole (37) in California did not find any relationship between husk length and resistance to earworm damage in either sweet or field corn. In a second paper, Poole (38) failed to find evidence to support the belief that long husk extensions or heavy husk covering is indicative of a high degree of earworm resistance. He contends that resistant varieties are descendants of types adapted in pre-Columbian day in regions where corn earworms were prevalent during all seasons and that the association of earworm resistance with southern varieties is a matter of coincidence rather than a genetic relationship. On the other hand, Hawthorne and Fletcher (27) found considerable correlation between husk characters and the degree of resistance to earworm attack.

Barber, (2) in a study of the preference of corn earworm moths for sweet corn for oviposition, found a range of 1.5 to 15 times the number of eggs laid on sweet corn as was laid on field corn which suggests another factor for resistance.

Ditman (22) discusses the earworm population in 1942 and the reasons for the large number. Ewing and Ivy (24) consider some of the factors affecting earworm population and damage with particular reference to the corn earworm as an enemy of cotton. They also discuss some of the predators of the earworm.

Dicke and Jenkins (20) attempted to identify inbred strains that contributed factors for protection against damage by earworms. They report the resistant strains had long husk that fit closely around and over the tip of the ear. The grain of resistant strains was above the average in content of hard starch either over the entire ear or over the tip of the ear. The long-husked strains of corn belt lines varied in degree of resistance as did the short-husked strains, suggesting that the long husk itself does not offer the maximum protection against earworm damage. The strains possessing the ability to withstand earworm attacks were the following: C.I.2, 23R7, C.I.6, C.I.7, Kys, J8-6G, J7-2E, 5675, C.I.33, 317Lh. Among these lacking resistance were WF9, 38-11, L317 and Hy. (Kys, L317, Hy in a double cross combination, and 38-11 were used in the present study.)

Cartwright (15) concluded that a long husk extension beyond the tip of the ear reduces the damage by the corn earworm. This relationship was found to be especially true in cases where the husk extension was four to five inches beyond the ear, in such cases the worms rarely reached the ears.

Blanchard, Bigger and Snelling (11) found resistance to be inherited. The single-cross hybrids in their tests were less severely damaged than the inbred lines. Some of the inbred lines transmitted a high degree of resistance even when combined in single-cross hybrids with a susceptible line. Variability in results was obtained with crosses involving a resistant and a susceptible line. The combination of two susceptible lines usually resulted in a susceptible single cross, but one case is cited in which a resistant single cross resulted from such a combination. Some inbred lines were stable in their resistance or susceptibility at the different localities included in the study.

Painter and Brunson (32) name several factors contributing to earworm resistance. The performance of some varieties, inbred lines and hybrids with regard to earworm resistance, is given.

In a study of the seasonal availability of host plants for the earworm, Barber (8) found eleven cultivated and seven wild species in eastern Georgia.

Barber (6) found that short husk, which increased earworm damage, could be caused by drought.

Methods and Materials

This investigation was conducted during 1945 in a corn field located two miles west of Stillwater, Oklahoma. The soil is a deep, permeable bottomland soil classified as Yahola very fine sandy loam, is slightly susceptible to overflow and had an average yield per acre of 40.9 bushels. The land was plowed to a depth of seven inches in November and received no further cultivation until five weeks before planting in the spring at which time it was cultivated twice with a disk harrow followed by planting with a check-row planter. The corn received frequent cultivations until size of the plants prevented further cultivation. Corn had been grown on part of this test area during the past four years. Although no counts were made of the moths or larvae present during the year, the population seems to have been very high since the number of worm-free ears was almost nil. It is possible that the earworm population in this field was higher than in other fields in the vicinity because of the presence of other host plants, such as cotton and alfalfa, in the same field.

Four replications of the United States Department of Agriculture's "Uniform Late Yellow Single-Crosses" were used in the test. All possible single-cross combinations of the lines T8, o4, L317, K201C, K155, Kys, K4, 38-11, H8, and K222 were used with the exception of some combinations of the lines H8 and K222 which were not included because the seed was not available. In addition to these single-crosses, 4 Oklahoma varieties, 9 double-cross hybrids and 1 top-cross hybrid were used, making a total of 49 hybrids and varieties. These hybrids and varieties were being grown primarily to test their relative potential agronomic qualities as a regular part of the corn improvement program carried on at

Oklahoma Agricultural and Mechanical College. Each variety and hybrid was planted in randomized plots, two rows wide and ten hills long.

Due to the continued rains at the regular planting season, the corn was not planted until April 24, two or three weeks after the preferred planting date. Because of prolonged wet weather and low temperatures, the young corn plants were retarded in their early growth period. Growth after the plants were three weeks old was rapid.

The range in the number of days from planting to the time at which 50 percent of the plants of the hybrids and varieties were in silk was from 82.8 to 90.0 days.

Measurements were taken of the husk lengths and tightness of the husks of each plot the first of August when most of the ears were in the milk stage. Some measurements were again taken at the time of harvesting, but upon finding no appreciable difference between these measurements and the previous ones, the task was abandoned. Each plot was harvested separately, stored in separate bags and each ear was examined separately for earworm damage. Two replications were used in scoring the degree of hard starch in the kernel cap. In measuring the degree of hard starch, a standard of five types was set up by a thorough examination of kernels from many of the different hybrids and varieties. One standard was selected for the highest degree of hard starch, one with the lowest degree and the intermediate standards. Each variety and hybrid was evaluated by these standards.

The lengths of the husk were scored as follows:

Length of husk	Length score
1 inch of ear exposed	-2
½ inch of ear exposed	-1
Equal husk and ear length	0

Length of husk (cont'd.)	Length score (cont'd.)
Husk extending $\frac{1}{2}$ inch beyond ear	1
Husk extending 1 inch beyond ear	2
Husk extending $1\frac{1}{2}$ inches beyond ear	3
Husk extending 2 inches beyond ear	4
Husk extending 3 inches beyond ear	5

The tightness of the husk was scored as follows:

Tightness of husk	Tightness score
Ear tip exposed	1
Loose husk	2
Medium husk	3
Tight husk	4

Worm-free ears were so rare that the class having no damages was included in the class having less than one-half inch of the ear damaged. There were two types of damage; early damage, or damage to the ear while the kernels were in the milk or dough stage and late damage or damage to the kernels after they were beginning to harden. In the late type of damage the kernel caps were eaten because the caps are the last portion of the kernels to harden. Worms arriving too late to feed on the kernels while they are in the milk or dough stage, attack the kernel caps provided they have not become too hard also. Early and late damage were recorded separately. When an ear had suffered both types of damage both were recorded for the same ear. Each class was given a number which was considered to be in proportion to the average relative amount of damage which occurred to ears falling in that class, that is, the class with greatest damage was considered to have four times the damage which occurred in the class of least damage.

The percent of the total number of ears, harvested from a plot, which fell in each class was multiplied by the class value and the product score of the five classes totaled to obtain the damage score for that plot.

The following table gives the classification of damage and the damage value or score.

Extent of Damage	Damage Score
0-½ inch of ear damaged	1
½-3/4 inch of ear damaged	1½
3/4-1½ inches of ear damaged	2½
1½-2½ inches of ear damage	3½
2½ inches of ear damage	4

Results and Discussion

In table 1 the hybrids and varieties are listed in an array from the one having the least amount of early damage to the one having the greatest amount. Thirty-three of the hybrids and varieties show significantly less early earworm damage than the most susceptible hybrid at the 1 percent level. There is a significant difference of 40 between the highest and lowest scores at the 1 percent level. Thirty-nine of the hybrids and varieties show significantly less damage than the most susceptible hybrid at the 5 percent level and there is a significant difference of 47 between the lowest damage score and the highest damage score at the 5 percent level. The large variation in early earworm damage scores is indicative of the differences existing between lines and varieties in ability to resist earworm attack and suggest great possibilities in breeding corn resistant to earworm ravages.

All of the native varieties studied in this test show significantly less early damage than the most susceptible hybrids. Average early damage score of the varieties was 16.7 lower than the average damage score of the hybrids. Yellow Surcropper had the least amount of both early and late damage and was followed in order by Southwestern Yellow Dent, Groenemans Mortgage Lifter and Reid Yellow Dent except that the late damage score for Southwestern Yellow Dent exceeded that of Groenemans Mortgage Lifter and Reid Yellow Dent. Average husk length scores of the varieties range from 1.25 in Yellow Surcropper and Southwestern Yellow Dent to 2.00 in Groenemans Mortgage Lifter. Groenemans Mortgage Lifter and Reid Yellow Dent had the tightest husk both having a score

TABLE I

EARWORM DAMAGE SCORES AND RELATIVE DATA FOR VARIETIES, HYBRIDS AND LINES IN SINGLE-CROSS COMBINATIONS.

Variety or Hybrid	Early Damage* Score	Late Damage Score	Husk Length Score	Husk Tightness Score	Hard Starch in the Kernel Caps Score	Days from Planting to Silking
H8 x K222	131	29.12	1.00	3.25	1	90.0
Kys x K155	134	0.73	2.75	3.75	3	85.5
Yellow Surcropper	136	3.55	1.25	2.25	1	85.0
Kys x K201C	136	6.32	1.00	3.00	2	87.0
K155 x K201C	138	5.70	3.50	3.00	1	86.3
Southwestern Yellow Dent	144	24.75	1.25	2.75	2	87.3
Kys x H8	144	11.64	.50	1.50	2	88.0
Kys x T8	145	3.26	.75	2.50	4	84.0
K4 x K201C	146	13.06	.25	1.00	2	88.0
38-11 x K4	147	14.88	1.50	2.75	1	86.0
Texas Hy.20(203 x Kys) x (127C x 132A)	148	10.20	.25	1.25	0	85.8
Tennessee Hy.4003(K4 x Kys) x (T8 x CI7)	148	9.56	.50	1.75	2	84.3
38-11 x K201C	148	15.69	1.25	2.75	4	86.3
K4 x K222	149	27.05	1.25	2.75	2	88.5
Groenemans Mortgage Lifter	150	7.05	2.00	3.25	1	86.8
38-11 x Kys	151	1.57	2.25	3.00	4	84.5
38-11 x H8	152	29.07	1.00	2.50	1	86.5
K201C x T8	153	8.23	.00	1.25	3	86.5
Texas Hy.8(Yellow Surcropper)x(127C x 132A)	155	19.50	.00	1.25	1	85.0
K4 x 04	156	9.91	.50	1.75	3	85.0
K4 x L317	156	15.99	1.00	2.50	2	85.3
K4 x H8	158	22.90	1.50	3.25	0	86.7
K4 x K155	160	6.47	3.50	3.50	3	86.7
K201C x L317	160	22.24	.50	1.75	2	85.0
K155 x 04	160	16.28	1.00	1.75	1	83.8

Table I, Continued

Variety or Hybrid	Early Damage* Score	Late Damage Score	Husk Length Score	Husk Tightness Score	Hard Starch in the Kernel Caps Score	Days from Planting to Silking
38-11 x K222	161	45.23	1.50	1.25	4	87.3
Reid Yellow Dent	164	12.56	1.50	3.25	2	86.3
Texas Hy.12 (K4 x Kys) x (127C x 132A)	164	43.06	.25	1.00	0	86.3
K201C x 04	165	20.19	-.25	1.00	2	85.3
K155 x T8	168	7.38	.25	1.75	3	83.8
38-11 x K155	168	17.21	3.00	2.75	3	85.5
Missouri Hy.8 (K4 x B2) x (L3 x G)	168	35.13	1.00	2.00	0	83.8
L317 x 04	168	14.49	.25	1.25	2	85.8
Kansas Hy.1585 (K155 x K201C) x (K4 x 38-11)	170	11.76	.50	1.75	2	84.5
Kys x 04	170	20.12	.00	1.50	1	84.5
Illinois Hy448 (38-11 x Kys) x (K4 x L317)	172	19.54	.75	2.25	2	85.8
K4 x Kys	172	23.23	1.50	3.25	3	88.0
38-11 x T8	175	8.40	-.25	1.00	4	85.5
H8 x 04	176	25.92	-.75	1.00	3	84.5
Kansas Hy.1583 (Kys x K201C) x (K4 x 38-11)	183	19.23	.25	1.25	2	85.0
Kys x L317	184	34.37	.50	1.75	1	85.0
Missouri Hy.148 (WF9 x 38-11) x (K4 x L3)	186	51.92	.25	1.25	2	83.8
38-11 x L317	189	48.00	.50	1.50	2	85.0
T8 x 04	191	6.00	1.25	1.00	4	84.5
U.S.Hy.379 (Hy x C.I.7) x (P8 x J8)	193	19.25	.00	1.75	2	82.8
K155 x L317	194	25.95	1.25	2.00	1	84.3
38-11 x 04	196	18.83	-.25	1.00	3	84.5
K4 x T8	198	9.10	-1.00	1.00	4	85.8
L317 x T8	202	31.62	-.75	1.00	3	83.3
Average	163.1	18.02	.79	2.01	2.1	85.6

* A difference greater than 23.210 and 30.645 at the 5 and 1 percent levels, respectively, is required for significance.

of 3.25. Yellow Surcropper had the lowest husk tightness score of the varieties with an average of 2.25. The average scores for hard starch in the kernel caps is relatively low in the varieties in comparison with hybrids being 1 for Groenemans Mortgage Lifter and Yellow Surcropper and 2 for Southwestern Yellow Dent and Reid Yellow Dent. A difference of only 2.3 days was found in the days from planting to silking in the varieties. Fifty-percent of the Yellow Surcropper plants were in silk 85 days after plantings and Southwestern Yellow Dent, the latest maturing variety, was 50 percent in silk 87.3 days after planting.

Among the top-cross and double-cross hybrids Texas Hybrid 20 and Tennessee Hybrid 4003 have the lowest early damage score at 148. Texas Hybrid 8 is only 7 higher with a score of 155. Missouri Hybrid 148 and U.S. Hybrid 379 show the least resistance with scores of 186 and 193 respectively. Missouri Hybrid 148 and U.S. Hybrid 379 also have higher late damage scores than the two hybrids most resistant to early damage. Texas Hybrid 12, although intermediate in resistance to early earworm damage, shows a high late damage score of 43.06. There seems to be some correlation between the factors of resistance in the top-cross and double-cross hybrids and the damage scores of each.

All of the lines involved in three of the double-cross hybrids mentioned above were included in the test. It is therefore possible to calculate the expected performance of these double-crosses and compare the calculated results with the actual damage score. The calculated score for Kansas 1583 is 154.3 and the actual score is 183.0; calculated score for Kansas 1585 is 155.6 and the actual score is 170.0; calculated score for Illinois 448 is 172.8 and actual score is 172.0.

The fact that the calculated damage score of some of the hybrids is near the actual damage score of the hybrids substantiates the theory that resistance to earworm attack is a heritable character. There seems to be some discrepancy in ability of the lines possessing high resistance to earworm attack to transmit that resistance to the hybrids in which they are used, which suggests a difference in compatibility of the lines.

The extent of late damage was not as great as that of early damage, the mean score of each being 18.02 and 163.10 respectively. This difference is due, chiefly, to the hardened kernels at the time when late damage occurred which lessened the attractiveness of the ear as food for the earworm.

The average husk length scores for each variety or hybrid varied from -1.25 to +3.50, tightness scores varied from 1.00 to 3.75, scores for hard starch in the kernel cap varied from 0 to 4 and the days from planting to silking from 82.8 to 90.0. The high degree of variance found in these factors for resistance is favorable to the plant breeder in selecting for resistance to earworm damage.

Single-cross hybrids are discussed in detail beginning on page 22. The coefficient of correlation for early earworm damage and late earworm damage is .3816 (Table II). The high correlation between the two types of damage indicates a relationship between the factors affecting resistance in early damage and those affecting resistance in late damage. The correlation of the factors of resistance with each type of damage substantiates the theory that there is a relationship between certain plant characters and resistance to both types of damage. There is little difference in the correlation of the two types of damage with either husk length or amount of hard starch in the kernel cap. There is a wide difference, however, in the correlation of husk tightness and the

TABLE II - MULTIPLE AND PARTIAL CORRELATION BETWEEN THE INDEPENDENT VARIABLES, HUSK LENGTH, HUSK TIGHTNESS, AND AMOUNT OF HARD STARCH IN THE KERNEL CAP, AND THE DEPENDENT VARIABLES, EARLY EARWORM DAMAGE AND LATE EARWORM DAMAGE.

Independent Variables or Variables	Dependent Variable	Coefficient of Correlation
Late Damage	Early Damage	.3816
All Independent Factors*	Early Damage	.5775
All Independent Factors*	Late Damage	.1948
Husk Length	Early Damage	.1590
Husk Length	Late Damage	.1414
Hard Starch in the Kernel Cap	Early Damage	.2490
Hard Starch in the Kernel Cap	Late Damage	.2945
Husk Tightness	Early Damage	.6780
Husk Tightness	Late Damage	.2273
Days from Planting to Silking	Early Damage	-.5856

*The independent factors, husk length, husk tightness, amount of hard starch in the kernel cap, are correlated with each type of damage to determine the additive effect they have on resistance to earworm damage.

two types of damage. This lower correlation of husk tightness with late damage might be explained by entry of the earworm by boring through the husk rather than entering at the tip.

Husk tightness, with a correlation to early damage of .6780, appears to be the greatest single factor in rendering corn resistant to early earworm damage. It exceeds the multiple correlation figure .5775 of husk tightness, husk length and hard starch in the kernel cap with early earworm damage by more than .10. Although the high coefficient of multiple correlation indicates that the factors of resistance are additive in effect and should all be considered in breeding for resistance, the extremely high correlation of husk tightness with early earworm damage suggests that a tight husk should be considered above the other factors thought to render corn resistant to earworm damage.

Correlation of husk length and hard starch in the kernel cap with early earworm damage is low in comparison to the correlation of husk tightness with early earworm damage. Correlation of husk length with early earworm damage is .09 lower than correlation of hard starch in the kernel cap with early earworm damage. The figures indicate that a high score in either husk length or hard starch in the kernel cap, unless occurring simultaneously and especially without a corresponding high score in husk tightness, is not too effective in yielding corn resistant to early earworm attack.

A shallow layer or the absence of a layer of soft starch in the kernel cap is the most effective factor measured in late earworm resistance. The correlation is .0997 above that of the multiple correlation of all three factors of resistance with late damage and more than twice the correlation of husk length with late earworm damage. It appears that in order for a variety or hybrid to be resistant to both types of damage, tightness of husk and a low degree of soft starch in the kernel cap or none at all are necessary, and length of husk being of lesser value than these two, nevertheless, is important and should be closely associated with husk tightness.

The correlation of days from planting to silking and early earworm damage was -.5856. The effectiveness of the silking date in earworm resistance depends on the plants silking before or after the height of the earworm moth population. The negative correlation between days from planting to silking with early earworm damage indicates that the early hybrids and varieties are more susceptible to early earworm damage. This high earworm damage score in the early varieties is attributed to the short, loose husk found generally on the early hybrids which are bred in the northern states where no selection is made for a long or tight husk. The early hybrids are not, therefore, considered more susceptible to earworm attack because of their earliness but the effect or earliness is thought to be masked by the loose and short husk found in the early hybrids and varieties.

Single-cross hybrid H8 x K222 (Table I) heads the list in low early earworm damage score, but these lines do not seem to transmit as high a degree of resistance when combined with other lines. Although they show a tight husk when crossed together, crosses of H8 and K222 with other lines have a lower husk tightness score. The amount of hard starch in the kernel cap and husk length is low in most single crosses containing these two lines. As previously mentioned, seed was not available for all combinations of these two lines, therefore they are not included in the summary tables 3-8.

Of the eight lines (o4, T8, L317, K201C, K155, Kys, K4, and 38-11), for which there were all possible combinations, K201C, Kys, K155, and K4 showed the greatest resistance to early earworm damage (Table III). These lines also showed the highest score on husk tightness (Table IV), husk length (Table V), and amount of hard starch in the kernel cap (Table VI) with the exception that 38-11 had a longer husk length and tighter husk than K201C and a greater amount of hard starch in the kernel cap than the other lines in combinations. Since 38-11 is fifth on the list of those lines transmitting a high degree of resistance in combinations, the fact that is has a higher husk length score and husk tightness score than K201C and a higher score for hard starch in the kernel cap than the four lines showing least amount of early earworm damage does not alter the theory that factors of resistance to damage correlate with resistance to damage. The occurrence of high scores for factors of resistance in the lines showing the most resistance suggests the use of lines possessing the factors for resistnace to earworm damage in the development of resistant hybrids.

Single-cross combinations of L317, T8 and o4 were found to have high early earworm damage scores (Table III). The lowest scores in husk length (Table V) and husk tightness (Table VI) were also found in these lines. Some discrepancy occurred in the scores for the amount of hard starch in the kernel cap when correlated with early earworm damage. T8 had the highest score for hard starch but showed least resistance to early earworm damage. This high score for hard starch shows up in the late damage scores (Table VII) with the T8 single-crosses having the smallest mean score damage of any of the lines for late earworm damage.

The single-cross combinations of L317 showed a high degree of late

TABLE III - SUMMARY OF RESISTANCE TO EARLY EARWORM DAMAGE OF EIGHT LINES IN ALL POSSIBLE SINGLE-CROSS COMBINATIONS.

	04	T8	L317	K201C	K155	KyS	K4	38-11
04		191	168	165	160	170	156	196
T8	191		202	153	168	145	198	175
L317	168	202		160	194	184	156	188
K201C	165	153	160		138	136	146	148
K155	160	168	194	138		134	160	168
KyS	170	145	184	136	134		172	151
K4	156	198	156	146	160	172		147
38-11	196	175	188	148	168	151	147	
Total	1206	1232	1252	1046	1122	1092	1135	1173
Average	172	176	179	149	160	156	162	168

TABLE IV - TIGHTNESS OF HUSK EXHIBITED BY EIGHT LINES IN ALL POSSIBLE SINGLE-CROSS COMBINATIONS.

	O4	T8	L317	K201C	K155	KyS	K4	38-11
O4		1.0	1.3	1.0	1.8	1.5	1.8	1.0
T8	1.0		1.0	1.3	1.8	2.5	1.0	1.0
L317	1.3	1.0		1.8	2.0	1.8	2.5	1.5
K201C	1.0	1.3	1.8		3.0	3.0	1.0	2.8
K155	1.8	1.8	2.0	3.0		3.8	3.5	2.8
KyS	1.5	2.5	1.8	3.0	3.8		3.3	3.0
K4	1.8	1.0	2.5	1.0	3.5	3.3		2.8
38-11	1.0	1.0	1.5	2.8	2.8	3.0	2.8	
Total	9.4	9.6	11.9	13.9	18.7	18.9	15.9	14.9
Average	1.3	1.4	1.7	2.0	2.7	2.7	2.3	2.1

TABLE V - HUSK LENGTH SCORES OF ALL POSSIBLE SINGLE-CROSS COMBINATIONS OF EIGHT LINES AND THE MEAN SCORE OF ALL THE COMBINATIONS.

	04	T8	L317	K201C	K155	KyS	K4	38-11
04		-1.3	0.3	-0.3	1.0	0.0	0.5	-0.3
T8	-1.3		-0.8	0.0	0.3	0.8	-1.0	-0.3
L317	0.3	-0.8		0.5	1.3	0.5	1.0	0.5
K201C	-0.3	0.0	0.5		3.5	1.0	0.3	1.3
K155	1.0	0.3	1.3	3.5		2.8	3.5	3.0
KyS	0.0	0.8	0.5	1.0	2.8		1.5	2.3
K4	0.5	-1.0	1.0	0.3	3.5	1.5		1.5
38-11	-0.3	-0.3	0.5	1.3	3.0	2.3	1.5	
Total	-0.1	-2.3	3.3	6.3	15.4	8.9	7.3	8.0
Average	-0.0	-0.3	0.5	0.9	2.2	1.3	1.0	1.1

TABLE VI - AMOUNT OF HARD STARCH FOUND IN ALL POSSIBLE SINGLE-CROSS COMBINATIONS OF EIGHT LINES.

	04	T8	L317	K201C	K155	KyS	K4	38-11
04		4	2	2	1	1	3	3
T8	4		3	3	3	4	4	4
L317	2	3		2	1	1	2	2
K201C	2	3	2		1	2	2	4
K155	1	3	1	1		3	3	3
KyS	1	4	1	2	3		3	4
K4	3	4	2	2	3	3		1
38-11	3	4	2	4	3	4	1	
Total	16	25	13	16	15	18	18	21
Average	2.0	3.1	1.9	2.3	2.1	2.6	2.6	3.0

as well as early damage. The mean score of late damage for combinations of this line ranges from 1.5 to 2.5 times the damage scores of the other lines. The hard starch score, which seems to be the greatest factor of resistance in late damage, is lowest in L317. The scores of this line for husk length and husk tightness, although not the lowest, rank third from the lowest in each case. Single-cross combinations of 38-11 and o4 rank next to L317 in high scores for late damage. The combinations of o4 rank next to those of the line having the least amount of hard starch and shortest husk and the least amount of tightness is found in the combinations of o4. The combinations of 38-11, which ranks next to L317 in having the greatest amount of late damage, ranks second in having the most hard starch in the kernel cap. The high degree of late damage in the combinations of 38-11 must then be contributed to the relatively short husk length and lack of tightness in the husk found in the combinations of this line.

There was a difference of 1.6 days found in the means, of the days from planting to date when 50 percent of the plants were in silk, in the combinations of the lines. o4, T8, and L317 silked about the same date, 84.8 days. K4, the last to silk, had a silk date of 86.4 and was closely preceded by K201C at 86.3 days.

TABLE VII - SUMMARY OF RESISTANCE TO LATE EARWORM DAMAGE OF EIGHT LINES IN ALL POSSIBLE SINGLE-CROSS COMBINATIONS.

	o4	T8	L317	K201C	K155	KyS	K4	38-11
o4		6.0	14.5	20.2	16.3	20.1	9.9	18.8
T8	6.0		31.6	8.2	7.4	3.3	9.1	8.4
L317	14.5	31.6		22.2	26.0	34.4	16.0	48.0
K201C	20.2	8.2	22.2		5.7	6.3	13.1	15.7
K155	16.3	7.4	26.0	5.7		0.7	6.5	17.2
KyS	20.1	3.3	34.4	6.3	.7		23.2	1.6
K4	9.9	9.1	16.0	13.1	6.5	23.2		14.9
38-11	18.8	8.4	48.0	15.7	17.2	1.6	14.9	
Total	105.8	74.0	192.7	91.4	79.8	89.6	92.7	124.6
Average	15.1	10.6	27.4	13.1	11.4	12.8	13.2	17.8

TABLE VIII - DAYS FROM PLANTING TO SILKING. SUMMARY OF THE PERFORMANCE OF EIGHT LINES IN THEIR TWENTY-EIGHT COMBINATIONS.

	o4	T8	L317	K201C	K155	KyS	K4	38-11
o4		84.5	85.8	85.3	83.8	84.5	85.0	84.5
T8	84.5		83.3	86.5	83.8	84.0	85.8	85.5
L317	85.8	83.3		85.0	84.3	85.0	85.3	85.0
K201C	85.3	86.5	85.0		86.3	87.0	88.0	86.3
K155	83.8	83.8	84.3	86.3		85.5	86.7	85.5
KyS	84.5	84.0	85.0	87.0	85.5		88.0	84.5
K4	85.0	85.8	85.3	88.0	86.7	88.0		86.0
38-11	84.5	85.5	85.0	86.3	85.5	84.5	86.0	
Total	593.4	593.4	593.7	604.4	595.9	598.5	604.8	597.3
Average	84.8	84.8	84.8	86.3	85.1	85.5	86.4	85.3

Summary and Conclusions

Considerable difference appears to exist among the hybrids and varieties in ability to withstand earworm attack and there seems to be considerable differentiation among the lines in transmitting resistance to earworm damage. All the native varieties exhibited a significant difference in resistance to earworm damage when compared to the most susceptible hybrids. Characters affecting resistance to earworm damage seem to be additive in effect and to correlate with the damage scores.

Early earworm damage scores are higher than late earworm damage scores. Apparently the difference is caused by the kernels becoming too hard to be attractive as food for the earworm at the time when late damage occurs. The high correlation between early and late damage indicates that the factors for resistance in early damage are also effective in late damage.

Husk tightness appears to be the greatest single factor of resistance for early damage. Correlation of hard starch in the kernel cap with early damage is higher than the correlation of husk length with early damage. Either tight husk or hard kernel caps, when present in the absence of the other factors of resistance, do not seem to be too effective in offering resistance to early damage.

A large amount of hard starch in the kernel cap probably is the most important factor in resistance for late damage. Tight husk seems to be more effective in resistance to late damage than long husk.

Lines K201C, Kys, K155 and K4 exhibit the greatest amount of resistance among the combinations of lines used in this test. Combinations of L317 show the least amount of resistance to both types of damage. A thorough study of the performance of the lines in transmitting characters of resistance and resistance to the combinations in which they are used indicates the possibility of developing resistance to earworm damage in hybrid corn.

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