GENETIC ANALYSIS OF STALK STRENGTH IN MAIZE

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Zuber and Loesch (1962) showed that rind thickness and crushing strength of second and third internodes of maize stalk were highly negatively correlated with stalk breakage and these two characters could therefore be good indices for the measurement of resistance to stalk breakage in maize. Since then, several workers have confirmed such negative correlations and have used crushing strength and rind thickness as measure of stalk breakage resistance.

A genetic analysis of these characters would be necessary for the formation of appropriate breeding procedures to improve stalk breakage resistance in the maize populations. Very scanty information was available in the literature about the inheritance of crushing strength, rind thickness, and stalk breakage in maize. Loesch, Zuber and Grogan (1963) reported that specific combining ability was of greater importance than general combining ability in the expression of crushing strength and rind thickness. However, Singh (1967b), in a study of gene action in maize inbred lines, reported that general combining ability was more important in the case of crushing strength and rind thickness, while for stalk lodging both general and specific combining ability effects were important. The present study, therefore, was undertaken to examine the type of gene action for these characters. This knowledge can be used effectively for improving the stalk strength and in turn resistance to stalk breakage in maize.

Materials and Methods

The material for the present investigation consisted of five inbred lines resistant to stalk lodging and five lines susceptible to stalk lodging under natural conditions and all possible 45 single crosses between these, omitting reciprocals. The pedigree of these inbred lines, code assigned to them and their lodging behaviour are presented in Table 1.

The material was grown in 1969 in a randomised block design with 3 replications at the Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar. Each genotype consisted of two rows. In order to get better control over error variance, the two rows of each genotype were randomised within a replication. Plot size, therefore, was one row of 10 meter length and row to row spacing was 0·75 meter. Two seeds per hill were planted at a distance of 23 centimeter apart and were thinned on the 28th day after sowing to one plant per hill.

Ten plants from each row were selected and observations were recorded using the techniques developed by Zuber and Grogan (1961). Data on crushing strength and rind thickness were collected on individual plants from the third internode of the stalk. Stalk breakage data were recorded just before harvest on the whole plot. Plants broken below the ear were counted in each row and percentage stalk breakage was calculated.

The data on stalk breakage, were subjected to the angular transformation for analysis. There was large variation for crushing strength and it was also found that the graph plotted between mean and

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TABLE 1

Details of inbred lines of maize used as parents

Pedigree	Code name	Reaction to lodging
1. Tx 325 C–1–1–≠–≠–≠	Tx 325C–1	Resistant
2. Eto–81B–≠–1–f–f–f–≠–1–≠–≠	Eto–81 B	Resistant
3. Eto–25–f–≠–1–f–f–f	Eto–25	Resistant
4. Eto–PL–13–1–≠–≠–1–≠	CM 300	Resistant
5. A Theo–21(B)–f–≠–3–f–≠–≠	CM 104	Resistant
6. G 751–A1–f–≠–≠–≠–≠	G 751–A1	Susceptible
7. Venz. 1–42–f–f–1–≠	Venz. 1–42	Susceptible
8. G 733–A96–f–≠	G 733–A96	Susceptible
9. P 5 PB 5–3–f	CM 102	Susceptible
10. P 4 A (Y)–1–3y–≠–≠	CM 101	Susceptible

standard deviation comes out to be a straight line with positive slope. Therefore, the data for this character were subjected to log 'x' transformation before analysis. Analysis of combining ability was carried out following the method given by Griffing (1956b). Graphic analysis and estimation of genetic components for variation were done using the methodology of Hayman (1954a), after testing the validity of assumptions by using the following formula with n–2 degrees of freedom:

$$t^2 = \frac{(n-2)}{4} (\text{Var. Vr} - \text{Var. Wr})^2 / \text{Var. Vr} \times \text{Var. Wr} - \text{Cov}^2 (\text{Vr, Wr}).$$

RESULTS

Highly significant differences were noted among the genotypes (Table 2).

TABLE 2

Analysis of variance for the characters studied

Source of variation	Degrees of freedom	Mean Square		
		Crushing strength	Rind thickness	Stalk breakage
Genotypes	54	0·1737**	0·0601**	168·72**
Experimental Error	108	0·0235	0·0127	12·24
Sampling Error	165	0·0169	0·0094	4·84
C.D. at 1% level		0·23	0·21	5·85

**Significant at 1% level of significance.

COMBINING ABILITY ANALYSIS

It was found that the variances due to both general and specific combining ability were highly significant for crushing strength, rind thickness and stalk breakage (Table 3). However, the variance for general combining ability was 2·1 and 3·6 times greater than that for specific combining ability in the case of crushing strength and stalk breakage, respectively, indicating a possible greater role of general combining ability in the expression of these characters. But in the case of rind thickness, relatively greater magnitude of specific combining ability variance (1·6 times) was indicated.

TABLE 3

Analysis of variance for combining ability for the characters studied

Sources of variation	Degrees of Freedom	Mean Square		
		Crushing strength	Rind thickness	Stalk breakage
General combining ability	9	0·0475**	0·0260**	166·59**
Specific combining ability	45	0·0224**	0·0417**	45·68**
Error	165	0·0028	0·0016	0·81

**Significant at 1% level of significance.

MEAN VALUES AND COMBINING ABILITY EFFECTS

Table 4 presents the estimates of general combining ability effects for parents and their mean values.

1. *Crushing strength*

Among the parental lines, Eto-25 had the highest crushing strength (2·56) and CM101 had the lowest (1·75).

Among single crosses, Eto-81 B×CM 102 had the highest crushing strength (2·73) and Tx 325 C-1 ×Eto-81 B had the lowest (2·38).

Inbred lines Eto-25 and CM 300 had highly significant positive values (0·078 and 0·068, respectively) for general combining ability effect indicating that these lines were good combiner for crushing strength. Line CM 101 and G 733-A 96 had highly significant negative estimates (–0·132 and –0·059, respectively), for general combining ability effect showing that these lines were poor combiner for crushing strength.

Line CM 101, which had the highest negative estimates for general combining ability effect (–0·132), however, gave positive (in some cases quite high estimates) specific combining ability effects in combination with all the parents except CM 102. Line CM 300, with highly significant positive general combining ability effect (0·068), in combination with G 751-A 1, also having

TABLE 4

General combining ability effects of parents and their mean values

Parents	Crushing strength			Rind thickness		Stalk breakage		
	Combining ability effect	Mean value		Combining ability effect	Mean value (in mm)	Combining ability effect	Mean value	
		Trans-formed	Original (in lb./sq inch)				Trans-formed	Original (in per-cent)
1	2	3	4	5	6	7	8	9
Tx 325C–1	0·011	2·477	299·9	–0·005	0·96	0·41	16·69	8·25
Eto–81B	0·016	2·358	228·0	0·022	1·01	–4·43**	10·03	3·06
Eto–25	0·078**	2·563	365·6	–0·004	1·12	–2·74**	2·42	0·19
CM 300	0·068**	2·484	304·8	0·083**	0·99	–5·12**	6·99	1·48
CM 104	0·016	2·462	289·7	–0·009	0·98	–2·39**	9·83	2·91
G 751–A1	0·016	2·363	230·7	0·007	0·93	2·12**	19·24	10·85
Venz. 1–42	–0·045*	2·063	115·6	–0·011	0·84	1·28**	25·51	18·55
G 733–A96	–0·059**	2·186	153·5	–0·051**	0·89	3·34**	27·72	21·64
CM 102	–0·033	2·317	207·5	0·050**	0·99	0·58*	17·73	9·29
CM 101	–0·132**	1·745	55·4	–0·081**	0·71	6·94**	46·28	52·23

positive general combining ability effect (0·016), gave highly significant negative estimate of specific combining ability effect (–0·194). Line Eto-25 with highest positive general combining ability effect (0·078) and the line CM 300 with second highest positive general combining ability effect (0·068) gave a cross with negative specific combining ability effect (–0·086).

2. RIND THICKNESS

Among the parents, Eto-25 had the highest rind thickness (1·12 mm) and CM 101 had the lowest (0·71 mm).

Highest rind thickness among the single crosses was observed in cross CM 300×CM 102 (1·25 mm). Cross G 733-A 96×CM 101 had the lowest rind thickness (0·93 mm).

Inbred lines CM 300 and CM 102 had highly significant positive values for general combining ability effect (0·083 and 0·050, respectively). This indicated that these lines had good general combining ability for rind thickness. CM 101 and G 733-A 96 had highly significant negative estimates of general combining ability effect (–0·081 and –0·051 respectively), thereby indicating their poor general combining ability for this character.

Venz. 1–42, which had negative general combining ability effect (–0·011), gave positive estimates of specific combining ability effect in combination with all the lines except Eto-25. Highest positive specific combining ability effect (0·127) was observed in a cross involving lines CM 102 with general combining ability effect 0·050 and Tx 325 C-1 with –0·005.

3. STALK BREAKAGE

Line Eto-25 had the lowest stalk breakage (2·42) among the parents. Highest stalk breakage was observed in case of CM 101 (46·28).

Single crosses Eto-81 B×Venz. 1–42 and Eto-81 B×CM 300 were the most resistant single crosses and did not show any stalk breakage. Highest stalk breakage among the single crosses was observed in case of CM 102×CM 101 (22·62).

Lines CM 101, G 733-A 96, G 751-A1 and Venz. 1–42 had highly significant positive estimates of general combining ability effect (6·94, 3·34, 2·12 and 1·28, respectively) indicating their tendency to produce combination susceptible to stalk breakage.

On the other hand, lines CM 300, Eto-81 B, Eto-25 and CM 104 had highly significant negative estimates of general combining ability effect (–5·12, –4·43, –2·74 and –2·34, respectively). This indicated that these lines had good combining ability to produce combinations resistant to stalk breakage.

Line CM 101, though with highest positive general combining ability effect (6·94), gave high negative estimates of specific combining ability effect in combination with all other lines except Tx 325 C-1 and CM 102. Line G 733-A 96, having highly significant positive general combining ability effect (3·34), in combination with CM 101, which had highest positive general combining ability effect (6·94) and with CM 104, having highly significant negative estimate of general combining ability effect (–2·34), gave highly significant negative specific combining ability effects (–19·34 and –10·31, respectively). Lines Eto-25 with general combining ability effect —2·74 and CM 104 with –2·34, gave the combination, having highly significant positive specific combining ability effect (7·83).

DIALLEL ANALYSIS

All the assumptions of diallel cross analysis were found to hold true as the t^2 value was found to be non-significant for all the three characters. Further coefficient of regression for all the characters was significantly different from zero and practically equal to unity (Table 5).

TABLE 5

t^2 values, regression coefficients and their test of significance for the characters studied

Type of tests	Crushing strength	Rind thickness	Stalk breakage
t^2	1·607 (NS)	0·149 (NS)	0·176 (NS)
b W_r, V_r	0·786±0·112	0·733±0·183	0·994±0·118
$\frac{b-0}{Sb}$	7·046**	3·919**	8·397**
$\frac{1-b}{S_b}$	1·919 (NS)	1·427 (NS)	0·054 (NS)

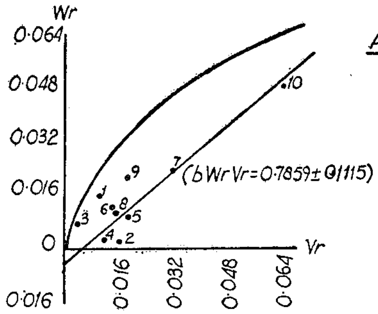
NS=Non-significant.
**=Significant at 5% level of significance.

GRAPHIC ANALYSIS

The (Wr, Vr) graphs for crushing strength, rind thickness and stalk breakage are presented in Figures 1, 2 and 3, respectively.

The regression line for crushing strength and rind thickness intersected the Wr-axis below the origin and for stalk breakage above the origin. This indicated that overdominance was responsible for the genetic determination of crushing strength and rind thickness, whereas for stalk breakage it was partial dominance.

A perusal of Figures 1 and 2 showed that array point for parent Eto-25 for crushing strength and CM 300 for rind thickness was nearest to the origin of the graph. This indicated the presence of maximum number of dominant genes in these parents for the concerned character. The array point for parent CM 101 occupied the position farthest to the origin for both these characters, indicating the presence of maximum number of recessive genes in this line for these characters. Mean value of parent Eto-25 in case of crushing



ARRAY POINTS	INBRED PARENTS
1	Tx325C-1
2	ETO-81B
3	ETO-25
4	CM-300
5	CM-104
6	G751-A1
7	VENZI-42
8	G733-A96
9	CM-102
10	CM-101

FIG. 1 CRUSHING STRENGTH

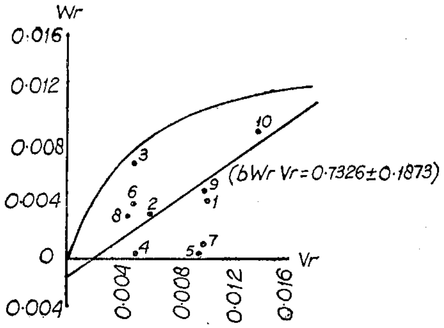


FIG. 2 RIND THICKNESS

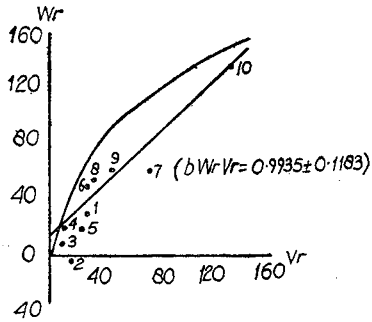


FIG. 3 STALK BREAKAGE

strength and CM 300 in case of rind thickness was highest, while that of CM 101 were lowest. This indicated that dominant genes were responsible for higher crushing strength and rind thickness.

For stalk breakage (Fig. 3), parent Eto-25 occupied the position nearest to the origin, indicating the presence of maximum number of dominant genes; whereas parent CM 101 was farthest to the origin, which indicated the presence of maximum number of recessive genes. Parent Eto-25 showed minimum stalk breakage, whereas CM 101 had maximum stalk breakage. This indicated that dominant genes were responsible for lower stalk breakage in the group of parents included in this study.

COMPONENTS OF VARIATION

The estimates of components of variation are presented in Table 6.

Highly significant values of both $\hat{D}$ ($0 \cdot 0620 \pm 0 \cdot 0052$; $t = 10 \cdot 00$) and $\hat{H}_1$ ($0 \cdot 0571 \pm 0 \cdot 0110$; $t = 5 \cdot 19$) indicated that additive and dominant variance

TABLE 6

Estimates of genetic components of variation for the characters studied

Components of variation	Characters		
	Crushing strength of third internode	Rind thickness of third internode	Stalk brekage
$\hat{D}$	0·0520**	0·0119**	128·93**
$\hat{F}$	0·0541**	0·0118	98·59**
$\hat{H}_1$	0·0571**	0·0213**	55·83*
$\hat{H}_2$	0·0408**	0·0140*	24·77
h^2	0·2549**	0·0563**	144·74**
$(H_1/D)^{0.5}$	1·04	1·33	0·65
$H_2/4H_1$	0·178	0·164	0·111
K_D/K_R	2·94	2·17	3·77
V_{ILI}/W_{OLOI}	1·33	2·33	0·91
$(D-H_1)$	N.S.	N.S.	S

*Significant at 5% level of significance.
**Significant at 1% level of significance.
N.S.—Non-significant.
S—Significant.

were both important in the determination of crushing strength in the set of maize materials included in this study. Similarly, for rind thickness, highly significant values of both $\hat{D}$ (0·0119±0·0025; t=4·76) and $\hat{H}_1$ (0·0213±0·0054; t=3·94) were observed, which indicated the importance of both additive and dominance variance in the determination of rind thickness. However, a greater magnitude of $\hat{H}_1$ estimate (1·8 times) in case of rind thickness indicated greater importance of non-additive genetic variance in the expression of this character. For stalk breakage, dominance component was significant only at 5% level, whereas additive component was significant at 1% level. Moreover the magnitude of additive component was also higher (2·3 times) as compared to that of dominance component for this character. This indicated the greater role of additive gene action in the determination of stalk breakage.

The average degree of dominance for crushing strength and rind thickness was in the range of overdominance, but for stalk breakage, it was in the partial dominance range.

The proportion of genes with positive and negative effects in the parents for all the characters under study appeared to be unequal, since $H_2/4H_1$ in all the three cases was found to be less than 0·25. Similarly, the proportion of dominant and recessive loci in the parents for these characters was not equal, as the K_D/K_R value was different from unity in all the cases.

Highly significant and positive value of F for crushing strength and stalk breakage indicate a greater frequency of dominant loci for these characters in the parents. On the other hand, non-significant F value for rind thickness indicated that the difference in the frequency of dominant and recessive loci for this character was not significant in the parents.

Discussion

Earlier studies conducted by Loesch *et al.* (1963) emphasised the greater role of specific combining ability, whereas those of Singh (1967b) laid emphasis on general combining ability in the expression of crushing strength and rind thickness, while for stalk breakage both effects were important. The present study showed that both general and specific combining ability variances were highly significant for all the three characters. But in case of crushing strength and stalk breakage general combining ability appeared to be of greater importance, while for rind thickness specific combining ability appeared to be playing a more important role. These observations are also supported by the estimates of components of genetic variation. Since the general combining ability is attributable to additive gene action and additive × additive epistatis, which is theoretically fixable, greater emphasis should be given to exploit additive genetic variance in the improvement of stalk breakage resistance in Indian maize germ plasm.

However, it would appear that in case of rind thickness non-additive genetic variance could also be used in obtaining hybrids having high rind thickness. This is also supported by graphic analysis which indicated that overdominance is involved in the genetic deter-mination of rind thickness as well as of crushing strength. It could, therefore, be possible to obtain combinations like Eto-81 B × CM 102, CM 300 × CM 102 and Tx 325C-1 × CM 102, having high crushing strength as well as rind thickness. Other combinations like Eto-25 × G 751-A1 for crushing strength and Tx 325C-1 × CM 300 for rind thickness could also be obtained.

For stalk breakage resistance, combinations like Eto-81B × CM 300, Eto-81B × Venz. 1-42, Eto-25 × CM 102, Eto-81B × CM 102, CM 104 × G 733-A96, G 733-A96 × CM 101 and CM 300 × G 751-A1, as such could be utilized. In most of these cases, either crushing strength or rind thickness or both were contributing to stalk breakage resistance. Crosses like Eto-25 × CM 102 and CM 104 × G 733-A96, had high degree of stalk breakage resistance and highly significant negative specific combining ability effects for stalk breakage. The specific combining ability effects of these crosses for crushing strength and rind thickness were non-significant. It is very interesting to note that cross Eto-81B × CM 300 showed no stalk breakage, though the specific combining ability effect for crushing strength, rind thickness and stalk breakage were non-significant. This indicates the operation of complementary gene action in some cases.

Inbred line CM 102 having high general combining ability for rind thickness, Eto-81B and CM 104 for stalk breakage resistance, Eto-25 for crushing strength and stalk breakage resistance and CM 300 for crushing strength, rind thickness as well as stalk breakage resistance could be used for developing synthetics with high stalk breakage resistance.

The significance of these findings is, however, limited by the fact the data represent observations of one year and one location only. The estimates of these genetic parameters are undoubtedly biased by genotype × environmental interaction.

Summary

Genetic analysis for rind thickness, crushing strength and stalk breakage indicated that both additive and non-additive genetic variances were important in the determination of these characters. However, in case of crushing strength and stalk breakage additive genetic variance appeared to be playing a greater role, while for rind thickness non-additive genetic variance played greater role. Dominant genes were responsible for higher crushing strength and rind thickness and for lower stalk breakage. Average degree of dominance was in the range of overdominance for crushing strength and rind thickness and for stalk breakage it was in partial dominance range.

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REFERENCES

Griffing, B. (1956b). Concept of general and specific combining ability in relation to diallel systems. *Aust. J. Biol. Sci.* **9:** 463–495.

Hayman, B. I. (1954a). Theory and analysis of diallel crosses. Genetics. **39:** 789–809.

Loesch, P. J. Jr., Zuber, M. S. and Grogan, C. O. (1963). Inheritance of crushing strength and rind thickness in several inbred lines of corn. *Crop. Sci.* **3:** 173–174.

Singh, T. P. (1967b). Gene action associated with certain traits in maize. *Indian J. Genet.* **27:** 429–432.

Zuber, M. S. and Grogan, C. O. (1961). A new technique for measuring stalk strength in corn. *Crop. Sci.* **1:** 378–380.

———, and Loesch, P. J., Jr. (1962). A mechanical method of evaluating stalk lodging. 17th *Ann. Hyb. Corn Industry Res. Conf. Amer. Seed Trade Assoc.*, pp. 15–23.