Genetical Analysis of Resistance to Root-lodging in Maize Based upon Discriminant Function of Biometrical Traits

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Introduction

Breeding for the resistance to lodging of crops is one of the most common and urgent targets of plant breeding, such as yielding ability, harvesting time, and so on. Recently machines for harvesting maize for whole plant silage have come to be widely used in Japan and, therefore, the resistance to lodging, that consists of root-lodging and stem (or stalk) breakage, has become one of the major breeding objectives in maize. However, enough information is not available on screening technique and genetics of the resistance to lodging in maize, especially in materials originated from our landraces, for hybrid breeding.

In the past three decades, several proposals of screening techniques for the resistance to lodging were made. Stem breakage was evaluated by the characters such as rind thickness, dry matter weight per unit length of stem[9] etc. Root-lodging** was evaluated by root system mass[7], and combined lodging, i.e., root-lodging combined with stem breakage was checked by restoring ability after hand-bending[4]. Lodging was induced experimentally under high population density with heavy-dressing of nitrogen-fertilizer and late planting[2]. Recently pulling resistance of maize is expected to serve as an indirect screening criterion for the resistance to root-lodging[1,6]. These techniques cited above employ all-or-nothing criteria, qualitative criteria, or non-parametric data, and hence it is very difficult to analyse the lodging resistance as numerical traits by these methods. Therefore, the authors[3] attempted to develop a screening criterion for root-lodging based on discriminant function and to make genetical analysis based on principal component analysis.

Evaluation of lodging resistance by using discriminant function

From the authors' observation on lodging in maize, it was found out that root-lodging which always resulted in cutting of many crown roots caused the loss of an entire plant, while stem or stalk breakage which occurs at the internode just upper or below the ear caused the loss of only an upper portion of plants. Based on this observation, the authors examined the root-lodging occurred before and after silking at the critical growing stage, and developed a criterion for screening the resistance to root-lodging by using discriminant function including four characteristics.

Seventy-seven materials, including 20 commercial hybrids, 26 inbred lines, 11 open-pollinated varieties, 11 synthetic lines and 9 experimental F_1s, were used to examine the relation of root-lodging to nine traits, i.e. pulling resistance, plant height, ear height, the

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** Lodging of a whole plant occurring at the ground level. Plants suffered root-lodging never recover, because crown roots are broken.

number of tillers, fresh and dry plant weight, gravity center, moment of the gravity and days to tasselling. In this study, the root-lodging was graded by the percentage of lodged plants showing their inclination more than 30° to the total number of plants used.

Grade	Percentage of lodged plants
1	0 – 10
2	10 – 20
3	20 – 50
4	50 – 70
5	70 – 100

Values of discriminant function produced from data of nine characteristics of 77 materials reflected almost completely the actual root-lodging occurrence in the field, with only one exception. Therefore, values of discriminant function can be used as expressing the actual lodging in the field, even when the lodging does not happen. The other preliminary data showed that three traits with closer relationship to root-lodging, namely, pulling resistance (X_1), fresh plant weight (X_2) and gravity center (X_3), are much conveniently used for discriminant function analysis. The discriminant function obtained with these three characteristics was as follows:

$$Z = 0.413 - 2.207\frac{(X_1-\mu_1)}{\sigma_1} + 0.315\frac{(X_2-\mu_2)}{\sigma_2} + 1.740\frac{(X_3-\mu_3)}{\sigma_3}$$

where μ_1, μ_2, μ_3, and σ_1, σ_2, σ_3 are means and standard deviations of each of the three characteristics in 77 materials, respectively. By this discriminant function obtained with these three characteristics, mis-interpretation of lodging resistant materials as lodging susceptible ones occurred with only four materials out of 77 materials. When the value of this linear function for a variety is negative, we can conclude that the variety is resistant to root-lodging.

The experiment conducted for four years, from 1978 to 1981, using 13 materials at two different locations, Hiratsuka and Tsukuba, showed that the value of the discriminant function for each of the materials was consistent as shown in Table 1. Thus, it was concluded that the discriminant function proposed here is effective to evaluate the resistance to root-lodging of maize, either inbred lines, hybrids, synthetics, or open-pollinated varieties, because of the stability of their values over years.

Table 1. Values of the discriminant function* for inbred lines, a synthetic line, and a commercial hybrid (1978 to 1981)

Materials	1978	1979	1980	1981
A 654	−2.2	−2.3	−2.1	—
CM 37	−1.7	—	1.1	0.8
CM 91	−4.0	−2.1	−1.6	—
D 94	2.6	2.3	2.4	2.3
N 206	—	—	3.7	2.6
Oh 43	−2.3	−2.2	—	—
Oh 545	−2.2	−2.7	−0.1	—
RB 259	−2.4	−2.5	−1.4	−0.4
W 182 B	1.9	—	3.1	1.8
W 59 E	−1.8	−4.7	−1.4	—
914-2	—	0.3	—	−1.2
Kichi Gosei 88	−0.2	0.0	−0.9	—
P 3715	−1.4	−2.0	−0.4	—

P 3715 is a hybrid variety introduced from Pioneer Seed Hybrid Co. Ltd., U. S. A.
* *cf.* the text.

Moreover, the conclusion mentioned here was further confirmed from the data obtained at different experimental sites, Obi-hiro and Sapporo in Hokkaido, Tsukuba, and Miyakonojo in Kyushu for two years. Although both actual lodging and values of the discriminant function varied in two years, parallelism between the actual lodging and the values existed in all the experimental sites. Therefore, it is concluded that the discriminant function makes it possible to evaluate the lodging resistance of materials planted to different locations in different years, when the materials include common check varieties.

Evaluation of the resistance to lodging by the principal component analysis

Principal component analysis is very effective to analyse plant populations which have multi-variate characters related to complex and numerical characteristics in plant genetics. For example, Watanabe[8] studied the resistance to lodging in rice plants by adopting principal component analysis and showed that the resistance was controlled by quantitative traits.

The data of characteristics obtained from the 77 materials were subjected to principal component analysis. Fig. 1 shows a scatter diagram of the first and second component scores. Materials with high resistance to lodging are distributed in the quadrants III and IV, while those more susceptible are included in the I and II. On the other hand, materials which give high yields as the whole plant silage are distributed in I and IV. It suggests that the second component score enables to evaluate the resistance to lodging, while the first one is associated with plant size.

Screening of materials for resistance to root-lodging

Root-lodging occurrence in the field and plant characteristics constituting the discriminant functions were examined with 13 inbred lines, 26 commercial F_1 hybrids, 2 synthetics and 4 open-pollinated varieties in 1979, 5 inbred lines and 30 experimental F_1s in 1981, and 74 experimental F_1s and 16 commercial hybrids in 1982. Actual root-lodging was not observed in 1979, but it occurred after measuring the plant characteristics in 1981 and before measuring them in 1982.

Looking through the three years' data, big differences among materials, either within F_1s or within inbred lines were recognized. The hybrids between resistant inbred lines showed negative Z-values indicating the resistance to root-lodging. Materials estimated to be resistant by the discriminant function were observed to be actually resistant against

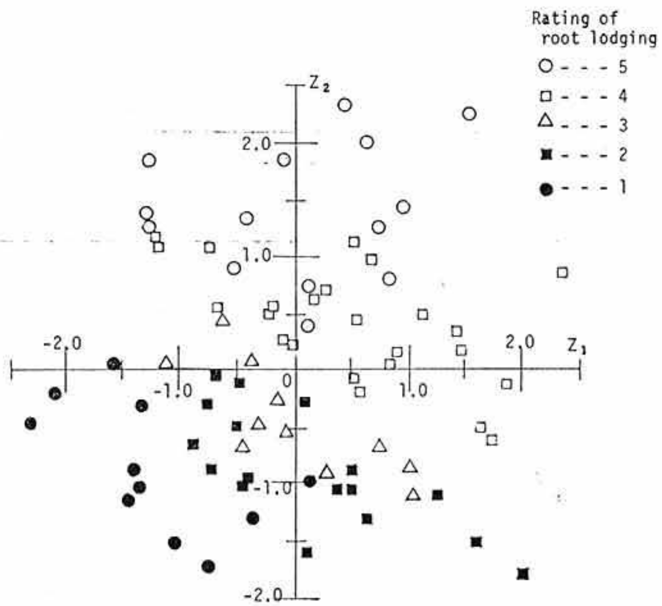

Fig. 1. Scatter diagram of every entry (1—77) for the first (Z_1) and the second (Z_2) principal component obtained by principal component analysis based upon 10 characters

the root-lodging in the field.

Resistance to root-lodging in F_1s and in their inbred lines

Results of our experiments showed much difference of root-lodging among inbred lines and among F_1s, like the difference in breakage[5]. Therefore, it is important to study the relationship between the resistance to root-lodging of inbred lines and that of F_1 plants in hybrid breeding.

With six inbred lines and their eight F_1 hybrids (Table 2) the resistance to root-lodging and Z-values were examined. On the 20th day after silking, plant height, gravity center, plant weight, and pulling resistance were measured with 8 to 15 plants in a plot.

Although actual root-lodging didn't occur in the field, values of discriminant function calculated from three characteristics showed precise differences among inbred lines and among F_1s (Table 2). It should be noticed that there was no heterosis in the value. Three F_1s of crosses among RB259, CM91 and A654 (all of which showed large negative values of discriminant function) showed the negative values also, whereas F_1s derived from other inbred lines didn't show negative values. Although heterosis in pulling resistance would appear, but no heterosis in the values of discriminant function as the criteria for the resistance to root-lodging appeared.

Secondly the authors made diallel analysis by using 5 × 5 crosses among five inbred lines including ones with large negative values or positive values (Table 3). In this analysis too, the result obtained was similar to the result mentioned above, showing no heterosis in the value of discriminant function, namely, in the resistance to root-lodging. From the analysis of variances of general and specific combining ability, a significant general combining ability on the value of discriminant function was shown, indicating that the mode of inheritance is additive. From these results obtained here, the authors concluded that the heterosis effect similar to that observed with other yielding ability cannot be expected (Fig. 2). However, it was suggested that the general combining ability of the resistance to root-lodging could be estimated in the parental inbred lines.

In order to breed an F_1 hybrid variety with

Table 2. Lodging resistance of inbred lines and their F_1s in maize

Line	Silking (days)	Plant height (cm)	Gravity center (cm)	Plant weight (g/plant)	Root pulling resistance (kgw)	Value of discriminant function
(Parent line)						
RB 259	65	104	44	331	49	−2.5
D 94	59	160	70	517	26	2.3
CM 91	62	90	40	301	44	−2.1
A 654	61	125	51	638	48	−2.3
W 49	62	105	43	270	18	0.6
Kichi Gosei 88	68	152	69	589	52	0.0
(F_1 hybrids)						
RB 259×D 94	61(63)	172(132)	76(57)	692(424)	53(38)	1.2(−0.1)
×CM 91	66(65)	130(97)	53(42)	425(316)	61(47)	−1.9(−2.3)
×A 654	61(64)	140(115)	62(48)	529(485)	78(49)	−2.9(−2.4)
×W 49	62(65)	158(105)	70(44)	640(301)	59(34)	−0.1(−1.0)
×Kichi Gosei 88	63(68)	156(128)	68(57)	612(460)	78(51)	−2.4(−1.3)
D 94×CM 91	65(63)	169(125)	99(55)	538(409)	56(35)	2.6(0.1)
×Kichi Gosei 88	65(66)	181(156)	86(70)	779(553)	59(39)	1.5(1.2)
CM 91 × A 654	62(64)	120(108)	58(46)	547(470)	85(46)	−4.0(−2.2)

Figures in parentheses refer to the mid-parental values.

Table 3. Mean values of traits related to resistance to lodging in 5×5 partial diallel cross

Materials	Plant height (cm)	Gravity center (cm)	Plant weight (g)	Root pulling resistance (kgw)	Value of discriminant function
CM 37	85(127)	44(63)	328(588)	28(50)	1.1(0.2)
CM 37×W 59 E	94	49	444	51	−1.2
N 21×CM 37	132	67	592	41	1.7
CM 37×N 206	146	69	662	49	0.9
CM 37×A 654	135	66	656	59	−0.6
W 59 E	55(118)	34(60)	204(563)	40(52)	−1.4(−0.3)
N 21×W 59 E	127	64	620	50	0.3
W 59 E×N 206	138	66	625	48	0.8
W 59 E×A 654	113	59	564	59	−1.2
N 21	118(144)	56(69)	489(661)	32(48)	1.8(1.1)
N 21×N 206	162	72	674	38	2.6
N 21×A 654	153	73	761	61	−0.1
N 206	172(154)	72(71)	516(692)	36(46)	2.6(1.6)
N 206×A 654	171	76	820	47	2.0
A 654	118(143)	60(69)	511(698)	50(56)	−0.1(0.0)

( ): Mean value of F_1s related to a given inbred line.

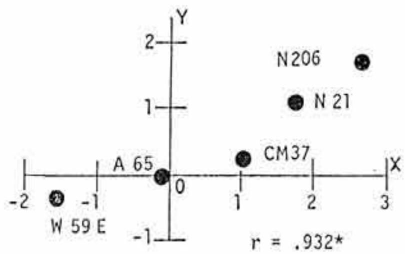

Fig. 2. Relationship between the discriminant values (X) of inbred lines and average ones (Y) in the F_1s related to the respective inbred lines

more resistance to root-lodging, plant breeders should select more resistant inbred lines as both parent lines. Recently Melchinger et al.[6] pointed out the similar conclusion, i.e., "select more resistant inbred lines to root-lodging for hybrid breeding". However, they said that phenotypic correlation between pulling resistance and root-lodging was not significant, though they didn't pay attention to other selecting criteria. The present authors' proposal that the resistance to root-lodging can be screened by using the value of discriminant function composed of three characteristics pertinent to root-lodging, in spite of a complicated nature of the resistance, seems to be very useful to breeding for lodging resistance.

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