# Correlation Coefficient Studies of Testers and Parents for Combining Ability in Sugar Beets

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Positive identification of superior germ plasm is probably the most important prerequisite to genetic progress in any breeding project. Without it, selection is random and genetic progress is a matter of chance. It has been generally accepted that broad gene-base testers are more efficient than narrow gene-base testers for the evaluation of general combining ability in inbred lines of maize as reported by Jenkins (5)[2], Matzinger (9) and Grogan and Zuber (4). Rawlings and Thompson (12) studied different maize testers and concluded that the apparent trends indicated by their data favored the lower performing tester.

Lonnquist and Lindsey (8) studied the performance of $S_1$ lines of maize using three types of test procedures: (a) lines *per se*; (b) test crosses to an unrelated synthetic tester; and (c) test crosses to the parental population. The observed phenotypic correlations for yield were highly significant. The mean yield of the $S_1$ lines was correlated with yield in top crosses with the unrelated tester ($r = .30$) and in top crosses with the related tester ($r = .27$). The correlation of yield of the two types of top crosses was also low ($r = .24$). The relationships were all too low to be of any predictive value.

Earlier work in maize by Nilsson-Leissner (10), Jorgenson and Brewbaker (7) and Jenkins (6) all showed positive but weak association between inbred yield and test crosses.

In crossing experiments with open-pollinated mother lines of sugar beets Doxtator and Skuderna (3) reported that when the average yield of parent lines was high, the resulting hybrid in most cases was high in yield. Positive and significant correlations were found for beet yield, sucrose percent and sugar per acre yield.

An economical method for testing general combining ability is needed if many sugar beet inbreds, sibs and/or strains are to be tested. For pseudo self-fertile beets, a top-cross plant with a dominant marker character has been used to produce crosses which could be identified in the seedling stage (1, 11, 12). Oldemeyer (11) reported a significant positive correlation between

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[2] Numbers in parentheses refer to literature cited.

the red-beet top crosses and a commercial tester parent for weight, percent sugar and sugar per acre. He also reported a high correlation for percent sugar between the inbred *per se* and the top cross performance using the red-marker tester. However, for weight this correlation was rather weak. Dickenson and Peterson (2) used the red-marker beet in crosses with several varieties. They concluded that the weight of the variety *per se* could not be taken as an indication of the level of general combining ability of plants within the variety. The correlation for percent sugar in their test also was positive and significant.

Test-cross evaluation procedures may vary somewhat, depending upon objectives of the program. In maize, the use of different testers to evaluate inbred lines for general combining ability, resulted in rather inconsistent selections of those indicated to be best. This is very disturbing. One source of inconsistency in test-cross evaluation is undoubtedly due to rather limited testing, such that genotype × environment interactions are contributing to selection inaccuracy. General combining ability is primarily a function of additive gene effects. Thus in tests for general combining ability it would appear worthwhile to consider line *per se* evaluation without the interference of the genetic contribution of the tester.

This study was based upon the evaluation of inbred diploid lines, several male-sterile strains and tetraploid populations using three types of test procedures as follows: (a) lines or strains *per se*; (b) test crosses to the red-marker beet; and (c) test crosses with several male-sterile strains.

## Materials and Methods

Four lines inbred for approximately four generations were each isolated with eight male-sterile strains in 1963. These isolations produced 32 diploid hybrids. Similarly, four newly created autotetraploid strains isolated with nine male-sterile diploid strains produced 36 triploid hybrids. Seven of the male-sterile parents were the same in each isolation. Three of the female parents in each isolation were inbred and quite uniform. The others were developed by at least three sib matings and perhaps were somewhat more variable.

A separate isolation plot was used for the red-marker tester parent. Roots of the male and female lines were planted in alternate rows with the red beet. Seed was harvested from only the parent lines. The percentage of seedlings having the red-marker characters was calculated from seed planted in greenhouse flats. A great diversity between lots as to the percent of identifiable hybrids was found due in part to different flowering dates. Planting rates were adjusted to the number of hybrids and the percent germination so each plot would have sufficient top-cross hybrids containing the red-marker gene.

The diploid and triploid hybrids were divided into two separate tests. The diploid test contained the twelve parents plus 32 hybrids from crossing the four inbred lines with the eight male-sterile lines. It also included the four males and the eight male steriles crossed onto the red-marker beets. Two commercial varieties were added, making a total of 58 entries.

The triploid test contained the four tetraploid males, the nine diploid male-sterile crosses and the 36 possible hybrids between them. It also included the 13 parents crôssed to the red-marker beet and two commercial varieties, making a total of 64 entries.

Each entry was replicated nine times in a randomized complete block design. A plot consisted of one row (22 inch row width) 35 feet long. The complete plot was harvested for weight and divided into two samples for sucrose determinations. Each test was planted at three locatons: Rocky Ford, Colorado; Mason City, Iowa; and East Grand Forks, Minnesota.

The data were analyzed by arranging the 32 diploid and the 36 triploid hybrids in a semi-diallel series for calculating general combining ability. The general combining ability means for the four inbreds contained 72 estimates (8 females and 9 replicates). The mean yield for the four tetraploid strains contained 81 estimates (9 females and 9 replicates). The mean yield results of the females in each test contained 36 estimates (4 males and 9 replicates). The yield results from the semi-diallel analysis should be the best estimate of general combining ability in these tests. The mean data from the semi-diallel series for both male and female were correlated with the yield obtained from the parents *per se* and with the parents × red-marker beet for both tests. The "r" values were averaged for each test over the three locations by using the "z" transformation. Covariance analyses were used to compute correlations, thus eliminating the variability among location means. A mean "r" value for both tests within locations was computed from the two covariance analyses by transforming each "r" to "z". A "t" test was used to determine if all "r" values were drawn at random from the same population.

## Results and Discussion

The correlation coefficients for the three diploid tests are shown in Table 1. The three tests were averaged by using the "z" transformation and the composite results also are shown in

Table 1.—Correlation coefficients for the diploid tests between the three types of combining ability testing procedures; for males, females and parents (males plus females) and for the composite and three individual locations.

| Type of testers | Rocky Ford | | | Mason City | | | East Grand Forks | | | Composite (using "z" values) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | df | Tons | % Sugar | df | Tons | % Sugar | df | Tons | % Sugar | df[1] | Tons | % Sugar |
| Diallel vs male *per se* | (2) | .948 | .788 | (2) | .782 | .499 | (2) | .885 | .795 | (3) | .891 | .716 |
| Diallel vs female *per se* | (6) | .434 | .809 | (6) | .508 | .754 | (6) | —.553 | .794 | (15) | .132 | .786 |
| Diallel vs parents *per se* | (10) | .541 | .747 | (10) | .611 | .637 | (10) | .174 | .794 | (27) | .460 | .732 |
| Diallel vs (male × red) | (2) | .475 | .976 | (2) | .984 | .560 | (2) | .746 | .486 | (3) | .861 | .808 |
| Diallel vs (female × red) | (6) | .716 | .206 | (6) | .174 | .374 | (6) | .025 | .214 | (15) | .354 | .266 |
| Diallel vs (parents × red) | (10) | .475 | .620 | (10) | .718 | .350 | (10) | .149 | .378 | (27) | .483 | .459 |
| Males vs (males × red) | (2) | .714 | .826 | (2) | .831 | .418 | (2) | .956 | —.099 | (3) | .867 | .515 |
| Females vs (females × red) | (6) | .507 | .315 | (6) | —.304 | .189 | (6) | .158 | .680 | (15) | .138 | .422 |
| Parents vs (parents × red) | (10) | .542 | .432 | (10) | .434 | .404 | (10) | .317 | .178 | (27) | .437 | .342 |

Significant at the 5% and 1% level of probability

| df | | 5% | 1% |
|---|---|---|---|
| 2 | = | .950 | .990 |
| 3 | = | .878 | .959 |
| 6 | = | .707 | .834 |
| 10 | = | .576 | .708 |
| 15 | = | .482 | .606 |
| 27 | = | .367 | .470 |

[1] Three degrees of freedom are lost for each "r" value converted to "z" value.

Table 1. The composite results should be the best general predictive values as they represent the performance of the hybrids and parents from three widely different environments. The means for the diallel results were the best estimates of combining ability, therefore the correlations of main interest are the semi-diallel and the parents *per se* and the semi-diallel and the crosses with the red-marker beet. The results differ considerably between the male and female parents. The "r" values for the diallel × male and diallel × (male × red) are fairly high for all locations and the composite for both tons and percent sugar. Although several of the "r" values were not significant at the five percent level they were approaching significance and might be used as predictive values. It appears that both of these combining-ability testing procedures would work equally efficiently, therefore the most economical procedure should be used.

The correlation values for testing females were considerably below the "r" values for males especially for tons. The relationships for predicting weight were too low to be of much value. The "r" values for percent sugar for the diallel × female *per se* were significant and could be used in predicting the combining ability for percent sugar.

These results show that the combining ability of inbred diploids used as males could be predicted fairly reliably by using either the parents *per se* or crosses to the red-marker beet. The combining ability of the females, which were not all inbreds, could not be predicted satisfactorily for tonnage yield. However, the combining ability of the females for percent sugar could be predicted by using the females *per se*.

The different results obtained between males and females may be due to the amount of homozygosity or heterozygosity which exists in the parents. The males in these tests were highly inbred and very uniform. Three of the females were inbred and uniform, while the other five contained some genetic variability.

Considering the "r" values of the parents as a group (4 males plus 8 females) for both weight and percent sugar, it appears that their yield *per se* was as good as any method used to predict their combining ability in hybrids. The percent sugar could be predicted with more reliability than tons.

The correlation coefficients for the three triploid tests and the composite are shown in Table 2. The highest predictive "r" values were again obtained between the diallel and the males *per se*. The "r" values for females and parents are considerably

Table 2.—Correlation coefficients for the triploid tests between the three types of combining ability testing procedures; for males, females and parents (males plus females) and for the composite and three individual locations.

| | Rocky Ford | | | Mason City | | | East Grand Forks | | | Composite (using "z" values) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type of testers | df | Tons | % Sugar | df | Tons | % Sugar | df | Tons | % Sugar | df[1] | Tons | % Sugar |
| Diallel vs males *per se* | (2) | .904 | .565 | (2) | .233 | .983 | (2) | .942 | .761 | (3) | .821 | .872 |
| Diallel vs females *per se* | (7) | —.081 | —.128 | (7) | .437 | —.391 | (7) | .799 | .355 | (18) | .462 | —.056 |
| Diallel vs parents *per se* | (11) | .029 | .078 | (11) | .339 | .299 | (11) | .754 | .456 | (30) | .425 | .283 |
| Diallel vs (male × red) | (2) | .907 | .163 | (2) | —.264 | .491 | (2) | .618 | .482 | (3) | .574 | .390 |
| Diallel vs (females × red) | (7) | .655 | .387 | (7) | .403 | —.629 | (7) | .397 | .473 | (18) | .495 | .061 |
| Diallel vs (parents × red) | (11) | .380 | .265 | (11) | .228 | —.104 | (11) | .368 | .447 | (30) | .328 | .215 |
| Males vs (males × red) | (2) | .688 | —.457 | (2) | —.248 | .460 | (2) | .793 | .206 | (3) | .507 | .072 |
| Females vs (females × red) | (7) | —.337 | —.447 | (7) | .288 | .451 | (7) | .479 | .331 | (18) | .156 | .116 |
| Parents vs (parents × red) | (11) | .289 | —.585 | (11) | .428 | —.286 | (11) | .564 | .162 | (30) | .437 | —.261 |

Significant at the 5% and 1% level of probability

| df | | 5% | 1% |
|---|---|---|---|
| 2 | = | .950 | .990 |
| 3 | = | .878 | .959 |
| 7 | = | .666 | .798 |
| 11 | = | .553 | .684 |
| 18 | = | .444 | .561 |
| 30 | = | .349 | .449 |

[1] Three degrees of freedom are lost for each "r" value converted to "z" value.

lower than for males regardless of the testing procedure. They are also lower than the "r" values computed for the diploid tests.

Covariance analyses were used to compute correlations which eliminated the variability among location means and these results are shown in Table 3. These "r" values probably represent the best estimates of the various relationships, however, they do not differ greatly from the composite results in Tables 1 and 2.

The creation of autotetraploid strains can be considered as a method of inbreeding because it becomes more difficult to segregate out individual genes, especially recessive genes. It then appears that it would be easier to predict the combining ability of nonsegregating strains, than to predict the combining ability of open-pollinated strains. A higher influence of the male parent on the triploid hybrid should be expected as the hybrid plants will receive two sets of genomes from the tetraploid parent. Likewise the evaluation of the females will have the interference of the genetic contribution of the tetraploids in the diallel series, which probably will cause lower "r" values.

Other reasons for lower "r" values in the triploid tests may be due to comparison at different chromosome levels. For example, the "r" values computed for the diallel vs males were from plants with triploid and tetraploid chromosomes, respectively; while the "r" values from the diallel vs females were comparing triploid and diploid strains. Similar comparisons of the diallel hybrids with the (males × red) and diallel vs (female

**Table 3.—Correlation coefficients computed from a covariance analysis for the three types of combining ability testing procedures for the diploid and triploid tests conducted at three locations.**

| Type of testers | Diploid test | | | Triploid test | | |
|---|---|---|---|---|---|---|
| | df | Tons | % Sugar | df | Tons | % Sugar |
| Diallel vs males *per se* | 8 | .867 | .727 | 8 | .795 | .785 |
| Diallel vs females *per se* | 20 | .314 | .774 | 23 | .270 | .162 |
| Diallel vs parents *per se* | 32 | .501 | .700 | 35 | .276 | .266 |
| Diallel vs (males × red) | 8 | .672 | .664 | 8 | .670 | .368 |
| Diallel vs (females × red) | 20 | .557 | .290 | 23 | .311 | —.015 |
| Diallel vs (parents × red) | 32 | .424 | .438 | 35 | .313 | .169 |
| Males vs (males × red) | 8 | .769 | .446 | 8 | .551 | .075 |
| Females vs (females × red) | 20 | .415 | .311 | 23 | .051 | .036 |
| Parents vs (parents × red) | 32 | .486 | .370 | 35 | .359 | —.259 |

Significant at the 5% and 1% level of probability

| df | | 5% | 1% |
|---|---|---|---|
| 8 | = | .632 | .765 |
| 20 | = | .423 | .537 |
| 23 | = | .396 | .505 |
| 32 | = | .339 | .437 |
| 35 | = | .325 | .418 |

× red) were at triploid and diploid chromosome levels, respectively. These differences in chromosome levels may partially explain why the various associations were not as high in the tetraploid tests as in the diploid tests.

The diploid and triploid tests were combined by using the "z" conversion tables and the results are given in Table 4. The correlation coefficients in Table 4 represent average predictive

**Table 4.—Correlation coefficients for the diploid and triploid tests between the three types of combining ability testing procedures; for males, females and parents (males plus females) for all locations.**

| Type of testers | n | df[1] | Tons | % Sugar |
|---|---|---|---|---|
| Diallel vs males *per se* | 20 | 14 | .835 | .769 |
| Diallel vs females *per se* | 47 | 41 | .291 | .509[2] |
| Diallel vs parents *per se* | 71 | 65 | .389 | .506 |
| Diallel vs (males × red) | 20 | 14 | .669 | .534 |
| Diallel vs (females × red) | 47 | 41 | .435 | .129 |
| Diallel vs (parents × red) | 71 | 65 | .364 | .304 |
| Males vs (males × red) | 20 | 14 | .675 | .272 |
| Females vs (females × red) | 47 | 41 | .228 | .169 |
| Parents vs (parents × red) | 71 | 65 | .423 | .044[2] |

Significant at the 5% and 1% level of probability

| df | | 5% | 1% |
|---|---|---|---|
| 14 | = | .497 | .623 |
| 41 | = | .301 | .389 |
| 65 | = | .241 | .313 |

[1] Three degrees of freedom are lost for each "r" value converted to "z" value.
[2] "t" test indicated the two values (diploid "r" and triploid "r") were not from the same population.

values for diploid, triploid, and/or tetraploid strains over several locations. These average "r" values indicated that males *per se* and/or (male × red beet) were highly correlated with the diallel results. These were nonsegregating genetic material. The average "r" values for females and parents *per se* or crossed with the red-marker beet are significant in some cases but are still too low to be used with any precision for predictive values.

The inconsistency of results from different testers at different locations is disturbing. One source of inconsistency in test-cross evaluation is undoubtedly due to limited testing, such that genotype × environment interactions are contributing to selection inaccuracy. From the above data it would appear worthwhile to consider line *per se* evaluation without the interference of the genetic contribution of the tester. On the other hand the "r" values with the red-marker beet are fairly high. This procedure had the advantages that all male and female parents could be placed in one large crossing plot and sufficient seed obtained to conduct several replicated tests. Using the male and female parent *per se,* each would require an isolation plot per parent.

It also appears that the red-marker beets may be more reliable when used with nonsegregating diploid material.

## Summary

This study was designed to evaluate the combining ability of sugar beet inbred diploid lines, several male sterile strains and tetraploid populations using three types of test procedures: (a) lines or strains *per se*; (b) test crosses to the red-marker beet; (c) test crosses with several male-sterile strains in a semi-diallel series.

Replicated tests were planted at three locations: Rocky Ford, Colorado; Mason City, Iowa; and East Grand Forks, Minnesota.

It was assumed that the best method of testing combining ability was by using a semi-diallel series of crosses. These results were correlated with the yield and percent sugar of strains *per se* and with test crosses with the red-marker beet. The following conclusions were drawn:

1. Yield and percent sugar of males *per se* were as good, if not a better criterion for determining combining ability than test crosses with a marker beet.

2. Higher correlations were obtained with nonsegregating material.

3. Correlations were generally higher for the diploid tests than for the triploid tests.

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