Combining ability of S3 maize inbred lines and related contributing traits for high yield under high population density

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Abstract. The productivity of maize may be increased by using maize hybrid ideotype (erect leaves and small leaf angles) which is adaptive under high plant population density. The hybrids maize was desirable in increasing the plant density due to better light interception and space so that it can increase the yield per unit area. The aim of the research was to assess S3 lines that had good combining ability and to determine the traits associated with high yields under high plant population density (83.333 plants/ha). A total of 242 hybrids (F1) were examined from a crossed combination of 121 lines x 2 tester were evaluated with three commercial hybrid varieties such as Bisi 18, P 27, and P 36. The evaluation was carried under high plant population density (83,333 plants/ha) in the rainy season (November 2020 – February 2021). The research used an alpha lattice design with three replications. The results showed that the inbred lines had a greater effect on the yield character and yield components, while the leaf angle and leaf orientation effected by the tester. The lines that had good general combining ability for high yielding were M3B11P27T3-11-3- 1, P27M3B11T3-1-4- 2, P27M3B11T3-1-2- 1, M3B11P27T3-8-4-1, P27M3B11T1 -1-1, M3B11P27T1-1-1- 3. The yield range of the hybrids were 8.43-9.90 t/ha, significantly higher than Bisi 18, P 27, P 36 varieties were 7.13 t/ha. Traits such as small leaf angle, erect leaf, root and stem lodging resistance, stem diameter, leaf length, ear diameter, and kernel row number were significantly correlated with high yield under high plant population density.

1. Introduction

The rate of maize production increase in Indonesia is 5.21% per year with the range of maize productivity approximately 5-9 t/ha [1]. This productivity has the potential to be boosted due to the agro-climatological potential for maize cultivation system in Indonesia [2]. Increased productivity of maize can be done by introducing high-yielding maize varieties with dense population cultivation [3,4]. Furthermore, adopting maize varieties with erect leaf ideotypes and small leaf angles enables to take advantage of space and sunlight interception that is more fit to tight planting and is expected to provide higher yield [4-8 ].

Several research indicated that plant population per unit area is among the most challenges as the productivity increases faster through planting maize with dense populations [5][9]. Ma et al. [10] also reported that one method to increases maize productivity in China is by growing maize varieties with erect leaf types and small leaf angles to enable more plant population density. Xue et al. [11] suggested
that generating maize varieties that are adaptive to dense populations in combination with improved yield potential per crop is among the most reasonable system.

Indonesian Cereals Research Institute (ICERI) in 2020 had collected over 283 S3 inbred lines with an erect leaf ideotype and a leaf angle of <25°. These inbreeds formed from four populations that is strictly selected with having small leaf angles and erect leaves. These lines are prospective parents of hybrid maize that can be used to develop hybrid maize varieties with the ideotype of erect leaves and narrow leaf angles which are expected to be cultivated with a population density over 83,000 plants/ha.

The existing inbred lines need to be properly combined. Combining ability analysis is one tool that is commonly used to identify inbred lines that having better combining ability to produce high F1 grain yield [12][13][14][15][16]. Information about the combining ability of an inbred is an important factor adopted in the process of effective hybrid breeding selection program. Therefore, this study was conducted in an effort to assess the combining ability of 121 S3 inbreds with the ideotype characteristics such as erect leaf type, small leaf angle and to determine relevant characters that contribute significantly high grain yields under dense populations.

2. Methodology

The research was conducted in two stages - the first stage was to generate F1 hybrid maize by using the Line x Tester method. The parental line consisted of 121 S3 lines which were segregated and selected based on the erect ideotype including erect leaf curve and leaf angle <25° from M3B11P27, P27M3B11, ErcCB, CY2B18, G9B11209, and M3B18 populations. The tester parents consisted of two inbred lines, i.e. CI301032 and CLYN 231. The crosses were carried out at the Bajeng Experimental Station, ICERI from June to October 2020.

The second stage was evaluation of agronomic and yield characteristics of 242 F1 hybrid derived from S3 inbred lines with erect and small leaf angles. Line x Tester method was used in the experiment. As control varieties, commercial hybrids of Bisi 18, P 27, and P 36. Were also planted in the experiment field. These hybrids were grown at IP2TP Bajeng in Gowa district, South Sulawesi. The study was conducted during the rainy season in November 2020 – February 2021. The soil in IP2TP Bajeng is classified as Inceptisol, with low to moderate fertility. The experimental design used was a randomized block design with three replications.

Each hybrid and inbred line was planted in a single row with 5 m length and spacing of 60 cm x 20 cm, equivalent to a population of 83,333 plants/ha. The dose of N fertilizer given was 175 Kg N/ha, P2O5 and K2O were each 100 kg/ha. Various parameters were observed including plant height, ear height, stalk diameter, leaf angle, leaf orientation score, leaf length, leaf width, root lodging, stalk lodging, ear length, ear diameter, shelling percentage, kernel number per row, row number per ear, and grain yields.

General combining ability and specific combining ability was calculated by using formula:

General combining ability:

\[ \text{Line (Parent)} = g_i = \frac{X_i}{tr} - \frac{X}{ltr} \]

\[ (\text{Tester}) = g_j = \frac{X_j}{tr} - \frac{X}{ltr} X_{ij} \]

Specific combining ability \( S_{ij} = \frac{r}{r} - \frac{X_i}{tr} - \frac{X_j}{ltr} + \frac{X}{ltr} \)

Where:

\( g_i \) : General combining ability of inbred line

\( g_j \) : Specific combining ability of inbred tester

\( S_{ij} \) : Effect of specific combining ability from crossing i and j

\( X \) : Total number

\( r \) : Number of replication

\( l \) : Number of inbred line

\( t \) : Number of inbred tester
3. Result and Discussions
Analysis of the variance indicates that sum squares based on the relative effect proportion of the inbred line, inbred tester and inbred tester interactions for several testcross hybrid maize characters showed that the inbred line effect was greater (>35%) than the tester inbred (<19%) and the interaction inbred line x tester (<15%) on the character of grain yield, ear diameter, leaf width and plant height, while the character of leaf angle and leaf curve pattern was influenced by the inbred tester (>40%) than the line inbred (<17%) or inbred LxT interactions (<12%) (Figure 1). This shows that the selection of the inbred line greatly determines the success in the formation of high productivity hybrid maize in dense populations, while the inbred tester greatly affects the ideotype characters of the plant canopy such as leaf angle and leaf curve scores.

![Proportion of Variance](chart.png)

**Figure 1.** Proportion of the value of the sum of squares from the analysis of variance of the influence of line inbred, tester inbred, and line x tester inbred interactions and the error on some characters of 242 testcross hybrids in a dense population

The two inbred testers CI301032 and CLYN 231 show different canopy ideotypes. Inbred tester CI301032 has erect leaves and small leaf angles and inherits these traits on to its hybrids, while the CLYN 231 tester inherits more drooping leaf types and large leaf angles. Based on the combining ability analysis, it was shown that the inbred CI301032 had a negative general combining ability score for both leaf angle (-3.07) and leaf orientation scores (-0.50) (Table 1). The negative general combining ability value indicated that the inbred inherited the character of small leaf angles and erect leaf curves. On the other hand, the CLYN 231 inbred tester had a positive combining ability value for leaf angle (3.07) and a leaf orientation score (0.50) (Table 1), indicating that the inbred inherited the character of a larger leaf angle and a drooping leaf curve.
3.1 Combining Ability of Inbred Line and Tester

The results of the general combining ability analysis showed that from 121 S3 inbred lines examined, 6 inbred lines perform significantly good combining ability for grain yield character i.e. M3B11P27T3-11-3-1, P27M3B11T3-1-4-2, P27M3B11T3-1-2-1, M3B11P27T3-8-4-1, P27M3B11T1-7-1-1, and M3B11P27T1-1-1-3 with the average yield of the two inbred testers 8.12 – 8.65 t/ha, a relatively higher than the commercial varieties with yields ranging from 7.10 to 7.13 t/ha (Table 1).

The Tetser CI 301032 inbred which has a good general combining ability value (GCA) for the yield character (0.77), a relatively higher than the CLYN 231 inbred with a GCA value of -0.77 ((Table 1). The good ones showed that they had good specific combining ability with the inbred tester CI 301032. The hybrids formed from crossing the six line inbreds that had good combining ability had higher productivity when crossed with the inbred tester CI 301032 with grain yield ranging from 8.57 - 9.90 t/ha (Table 1) The hybrids were significantly higher than the commercial varieties Bisi 18, P 27 and P 36 with grain yield ranging from 7.10-7.13 t/ha (Table 1).

Six S3 line inbreds which were identified as having good general combining ability for yield characters could be utilized in the program for the formation of hybrids that have high seed yields in dense populations. The Line S3 inbred can be continued with more stable (homozygous) breeding program [17].

Inbred lines that had good general combining ability for the characters of small leaf angle (-1.48) and erect leaf curve (-0.55) were P27M3B11T3-1-2-1 and M3B11P27T5-1-2-1 (Table 2). The inbred line will inherit the nature of the small leaf angle and the erect leaf curve on the hybrid. Thus, the character of plants that have a leaf canopy ideotype, plants that have small leaf angles and upright leaves are more adaptive to planting in dense populations than plants that have large leaf angles and drooping leaf curves [7,18].

**Table 1.** General combining ability (GCA) and specific combining ability (SCA) effects of 121 inbred lines and 2 inbred testers evaluated for grain yield

| No. | Line               | GCA for Yield | SCA for yield | Yield of F1 (t/ha) |
|-----|--------------------|---------------|---------------|-------------------|
|     |                    | CI 30032      | CLY231        | CI 301032 | CLY231 | Average |
| 1   | M3B11P27T3-11-3-1  | 0.47 *        | 0.17          | 0.06       | 9.90   | abc     | 7.40 | 8.65 |
| 2   | P27M3B11T3-1-4-2   | 0.46 *        | 0.58          | 0.41       | 8.43   | 8.10 | 8.27 |
| 3   | P27M3B11T3-1-2-1   | 0.41 *        | 1.66 **       | -0.03      | 9.23   | abc     | 7.17 | 8.20 |
| 4   | M3B11P27T3-8-4-1   | 0.39 *        | 0.77          | 0.16       | 9.43   | 6.97 | 8.20 |
| 5   | P27M3B11T1-7-1-1   | 0.44 *        | 0.99 *        | 0.54       | 9.03   | abc     | 7.33 | 8.18 |
| 6   | M3B11P27T1-1-1-3   | 0.38 *        | 0.43          | 0.95       | 8.57   | 7.67 | 8.12 |
| 7   | M3B11P27T3-8-1-3   | 0.35           | 1.16 *        | 0.06       | 9.40   | abc     | 6.30 | 7.85 |
| 8   | CB21-4-5-3         | 0.30           | 0.86          | 0.55       | 8.67   | 6.83 | 7.75 |
| 9   | M3B11P27T3-8-1-1   | 0.16           | 0.59          | -0.05      | 8.83   | abc     | 6.23 | 7.53 |
| 10  | M3B11P27T3-6-2-1   | 0.28           | 0.55          | -0.24      | 8.77   | abc     | 6.23 | 7.50 |
| 11  | M3B11P27T3-11-3-2  | 0.27           | 1.16 *        | -0.76      | 9.47   | abc     | 5.27 | 7.37 |
| 12  | G9/B11-209BC1-3-5-1| 0.19           | 0.44          | 0.40       | 8.53   | abc     | 6.03 | 7.28 |
| 13  | M3B11P27T3-8-1-2   | 0.16           | 0.51          | -0.18      | 9.00   | abc     | 5.53 | 7.27 |
| 14  | P27M3B11T3-2-1-1   | 0.15           | 0.86          | -1.02 **   | 8.10   | abc     | 5.93 | 7.02 |
| 15  | M3B11P27T3-8-3-1   | 0.15           | 1.42 **       | -0.47      | 8.90   | abc     | 5.10 | 7.00 |
| 16  | M3B11P27T1-1-2-2   | 0.13           | -0.55         | 1.01 *     | 6.13   | 7.77 | 6.95 |
| 17  | P27M3B11T1-5-1-1   | 0.13           | 0.99 *        | -0.33      | 7.87   | 5.90 | 6.88 |
| 18  | M3B11P27T3-11-1-1  | 0.11           | -0.51         | 1.07 *     | 6.40   | 7.20 | 6.80 |
| 19  | P27M3B11T19-2-3-6  | 0.09           | 0.98 *        | -0.53      | 8.57   | 4.60 | 6.58 |
| 20  | M3B11P27T3-7-1-2   | 0.09           | 1.22 *        | -0.70      | 7.50   | 5.60 | 6.55 |
| 21  | M3B11P27T5-1-2-1   | 0.04           | -1.12 *       | 1.26 *     | 5.93   | 7.17 | 6.55 |
| 22  | P27M3B11T8-2-2-1   | -0.26          | -1.10 *       | 0.15       | 5.77   | 5.97 | 5.87 |
| 23  | P27M3B11T19-1-1-1  | -0.27          | -1.02 *       | 0.00       | 5.73   | 5.90 | 5.82 |
| No.  | Line                  | leaf angle | leaf orientation score | Leaf width | leaf length | Plant height | Ear height | % Root lodging | % stalk lodging |
|------|-----------------------|------------|------------------------|------------|------------|--------------|------------|----------------|----------------|
| 1    | M3B11P27T3-11-3-1     | -0.67      | -0.21                  | 0.21       | 0.47       | 6.64         | 1.98       | 2.25           | 0.01           |
| 2    | P27M3B11T3-1-4-2     | -0.49      | 0.12                    | 0.30       | -0.35      | -1.35        | 0.51       | -0.65          | -0.12          |
| 3    | P27M3B11T3-1-2-1     | -1.48      | -0.55 **                | -0.06      | 1.32       | 1.35         | -0.71      | -1.21          | 0.05           |
| 4    | M3B11P27T3-8-4-1     | -0.39      | -0.05                   | 0.32       | 0.30       | 4.40         | 0.39       | -0.77          | -0.04          |
| 5    | P27M3B11T1-7-1-1     | -0.44      | 0.12                    | -0.01      | -1.13      | 4.53         | -0.55      | 1.02           | -0.04          |
| 6    | M3B11P27T1-1-1-3     | -0.21      | -0.05                   | 0.12       | 2.39       | -7.27        | -0.18      | -0.21          | 0.17 *          |
| 7    | M3B11P27T3-8-1-3     | -0.60      | -0.38                   | -0.05      | 1.00       | 2.24         | 0.99       | -1.32          | 0.01           |
| 8    | CB21-4-5-3           | 0.87       | -0.05                   | 0.38       | 2.59       | 10.24        | 2.30       | -0.10          | 0.01           |
| 9    | M3B11P27T3-8-1-1     | 0.71       | 0.12                    | -0.17      | -1.49      | 0.93         | 1.07       | -0.43          | 0.04           |
| 10   | M3B11P27T3-6-2-1     | -0.65      | -0.21                   | 0.57 **    | 1.53       | -4.69        | -0.99      | 0.80           | -0.08          |
| 11   | M3B11P27T3-11-3-2    | 0.50       | -0.05                   | -0.13      | 0.63       | 0.68         | -0.17      | -1.55          | 0.06           |
| 12   | G9/B11-209BC1-3-5-1  | -0.14      | 0.12                    | -0.09      | 0.38       | 2.45         | 0.91       | 1.35           | 0.06           |
| 13   | M3B11P27T3-8-1-2     | -0.05      | -0.38                   | 0.04       | 1.36       | 9.69         | 2.52 *     | 0.13           | -0.03          |
| 14   | P27M3B11T3-2-1-1     | 0.18       | -0.05                   | 0.06       | -2.96      | -4.06        | -2.57 *    | -1.55          | -0.08          |
| 15   | M3B11P27T3-8-3-1     | 1.91       | -0.21                   | 0.06       | 1.61       | -1.27        | -0.84      | 0.02           | -0.09          |
| 16   | M3B11P27T1-1-2-2     | 0.50       | 0.12                    | 0.01       | 2.10       | 3.05         | 0.14       | 0.02           | -0.03          |
| 17   | P27M3B11T1-5-1-1     | -1.18      | -0.21                   | 0.31       | 0.38       | 10.36 *      | 0.11       | 0.02           | -0.05          |
| 18   | M3B11P27T3-11-1-1    | -0.42      | -0.21                   | -0.03      | 0.10       | 4.40         | 0.67       | -0.21          | -0.07          |
| 19   | P27M3B11T19-2-3-6    | -0.42      | -0.38                   | 0.17       | -0.35      | 3.60         | 1.10       | 0.35           | -0.07          |
| 20   | M3B11P27T7-1-2-2     | 0.71       | -0.05                   | -0.22      | -1.29      | -1.52        | 0.55       | 1.47           | 0.03           |
| 21   | M3B11P27T5-1-2-1     | -0.12      | -0.71 **                | -0.33      | -2.47      | -11.59 **    | 0.30       | 0.80           | -0.07          |
| 22   | P27M3B11T18-2-2-1    | -0.23      | 0.12                    | 0.15       | 1.28       | 4.95         | 2.21 *     | -0.88          | 0.03           |
| 23   | P27M3B11T19-1-1-1    | -0.46      | -0.05                   | -0.26      | -4.80 *    | 3.13         | 0.94       | -1.21          | -0.08          |
| 24   | M3B11P27T6-3-2-1     | 0.48       | 0.12                    | 0.15       | 0.26       | 2.62         | -0.15      | 1.80           | 0.03           |
| 25   | M3B11P27T3-8-1-4     | -0.46      | 0.45 *                  | -0.18      | 2.22       | -0.46        | -1.00      | 3.36 *         | 0.10           |
3.2 Correlation of several plant characters with yield under high population density

Plant characters such as leaf angle, leaf orientation score, stalk diameter and leaf length were significantly correlated with seed yield in dense populations with correlation coefficient values < -0.45 or > 0.45 (Figure 2). The negative value of caffeine correlation with yield on the character of small leaf angles and leaf curves indicates that to obtain high yields in dense populations, an ideotype of plants with small leaf angles and upright leaf curves is needed.

Leaf angle, leaf size and shape are important components of maize leaf architecture. The number and distribution of leaf area and leaf angle in the canopy determine how solar radiation is captured for photosynthesis which affects maize yields in densely populated plantings [6]. The selection of more erect leaf types as the main target for selecting adaptive maize genotypes in dense populations [4] [19].

The large maize stalk size was significantly correlated with seed yield in dense populations. The positive correlation value (0.49) indicated that large maize stalk sizes supported high yields in dense population maize plantings. The dense population causes the plants to be etiolated to seek light so that the plant height becomes large and the stem size becomes small and weak. This increases the risk of plant fall which results in reduced yields [20][21]. Correlation analysis showed that the percentage of plant fall due to root or stem fall was significantly negatively correlated with yield (Figure 2). The larger the fallen plant, the greater the decrease in yield. A large stem size will be stronger to support plants in dense populations, thereby reducing the rate of plant fall compared to a small plant stem size. The selection criteria for stem size is one of the characteristics of adaptive inbred selection in dense populations.

Figure 2. Correlation between agronomic character and yield in dense population
4. Conclusion
The inbred line (L) has a greater effect than the inbred tester (T) or the L x T interaction on the grain yield, ear diameter, leaf width and plant height characters, while the leaf angle and leaf curve patterns are more likely influenced by the inbred tester.

The 6 inbred lines had significantly good combining ability for the grain yield characters, including M3B11P27T3-11-3-1, P27M3B11T3-1-4-2, P27M3B11T3-1-2-1, M3B11P27T3-8-4-1, P27M3B11T1-7-1-1, and M3B11P27T1-1-1-3. These inbred lines had a good combining ability with the inbred tester CI 301032 with grain yields obtained from hybrids ranging from 8.57-9.90 t/ha, significantly higher than the commercial varieties Bisi 18, P 27 and P 36 with yields ranging from 7.10-7.13 t/ha. The S3 line inbred can be continued with more homozygous inbred breeding.

Inbred lines P27M3B11T3-1-2-1 and M3B11P27T5-1-2-1 have good general combining ability for the character of small leaf angles and erect leaf curves. These inbreds can be used to assemble maize varieties with the ideotype of erect leaf canopy and small leaf angles that are adaptive to dense populations. Plant characters such as leaf angle, leaf orientation score, stalk diameter are important selection characteristics of maize leaf architecture that are adaptive to dense populations.

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